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13. ABSTRACT

The purpose of this research project is to apply the systems approach to the tunneling process and to the materials handling function in particular. This report deals primarily with the computer simulation model. A review of simulation methods and languages is presented first to provide background for the choice of a language and the development of the model.

The description of the computer model occupies a large portion of the report. The principles of simulation of each of the unit operations is discussed with the muck generation and the materials handling subsystems receiving the bulk of the attention. The method of testing out the program is also discussed. A guide to the use of the computer program is provided including a flow diagram of the computer logic, a section defining important variables, and a listing of the program.

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TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

The prime purpose of this research project is to apply the systems approach and the technique of computer programming in an attempt to improve the process of tunneling by rapid excavation methods. One specific objective is the optimization of the materials handling function for tunneling systems. This report contains information on the methods of simulation on the digital computer, the development of the computer model from the basic concepts, the guide to the use of the program, and the computer program itself.

The review of simulation methods contains a basic definition of simulation and a description of the most useful types of models for digital computers. Primary attention was given to the stochastic and deterministic conceptual models which are used in the simulation of tunneling systems and to methods of updating the computer simulation time variable. In addition, a discussion of computer languages for possible use in a simulation model is presented. The FORTRAN language was chosen for use in the model based primarily upon its wide acceptance and its familiarity to potential users.

The description of the computer model contains a synopsis of the objectives of the model as well as an outline of the concepts used in the simulation program. The discussion of the specific concepts applied is divided into sections dealing with the individual unit operations: muck generation, materials handling, roof support, and environmental control. An additional section deals with the general concepts used

throughout the program. The most detailed discussions deal with the muck generation and the materials handling subsystems which are the most complex unit operations to be modeled in the program. The materials handling methods receive the greatest analysis since they are the most complex from a systems standpoint and are the most difficult to simulate.

The attempts at testing the computer program are described in a separate section of the report. At present, the program has been debugged and the logic and behavior of the model during simulation have been studied using data obtained primarily in the field. No attempts have yet been made to check the accuracy of the computer model as this phase of the testing program is scheduled in the near future.

The final section of this report is a users' guide to the computer program, a list and description of the most important variables contained in the program, and a listing of the computer program.

ACKNOWLEDGEMENTS

The investigators would like to sincerely thank the following people and organizations who made contributions to this project. They provided a significant amount of assistance and contact with the real world which is necessary in a research endeavor of this type.

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SIMULATION BACKGROUND

The term "simulation" is used quite frequently in modern technical literature as the methods of computer modeling have become more widely applied and accepted. This section of the report provides a brief outline of the simulation methods and languages and defines the simulation terms used throughout the report.

Definition of Simulation

Simulation has been defined in numerous ways, but a definition that appears in a book by Pritsker and Balintfy (9)* appears to be most applicable here. They have said that "Simulation is the use of a model to study a problem." This simple yet concise definition describes very well the approach used in this project. Our problem is to improve or optimize the unit operations of a rapid excavation system, especially the materials handling subsystem. The model used will be a mathematical one, constructed for use on a digital computer.

The process of modeling is normally carried out in a series of five steps generally referred to as the scientific method. The scientific method of making decisions is often referred to as the systems approach and generally consists of the following steps:

1) Definition and breakdown of the system
2) Construction of a model of the system

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*The numbers in parentheses refer to the numbered publications in the REFERENCES section.

3) Testing of the model

4) Solution of the problem

5) Implementation of the solution

This year's work is involved primarily with the first two steps above, beginning with the definition of the problem and continuing through the construction of the computer model of the system.

Types of Simulation Models

In order to simulate any particular process or system, some type of a model is required. Several types of models exist, but only three general types are extensively used. These are the physical models, the analog models, and the conceptual models.

A physical model is a physical model or replica of a system, generally scaled down to a size which is more easily handled than the full-size system. The usual reason for using a physical model is economy of operation. The model can be used to simulate the operation of the actual system without incurring the cost of the full-scale system. Physical models are seldom used in systems analysis but can often be used in other fields of engineering such as in aeronautical evaluation of aircraft design. A physical model is easy to "understand" since looks like the object that it represents or models.

The second class of simulation models are the analog variety. An analog model is a system, such as an electrical or hydraulic circuit, which can be constructed to relate

to another system in such a manner that the behavior of the model can solve problems in the analogous system we are interested in. A typical example of this type of model is the electrical network analyzers used to solve problems related to mine ventilation circuits. Analog models are useful only in certain types of problems, but provide rapid, convenient answers in situations where they apply.

The conceptual models, often called logical or mathematical models, are the prevalent model type and are put to use on a wide variety of problems. For this type of model, the components of the system are represented by mathematical formulas, probability distributions, or numerical data which is used to model the system. A mathematical model is normally written in a computer language so that the massive chore of performing the simulation may be done by computer. Most of the mathematical simulation models fall into the class known as the Monte Carlo methods. In these methods, the general approach is to run and rerun the simulation process as a statistical experiment, measuring the results in order to learn something about the process simulated. The Monte Carlo methods are subdivided into the stochastic and deterministic models.

Stochastic Simulation. Stochastic or probabilistic simulation models are used in situations where the elements of the model are probabilistic or random in nature, i.e.,

the elements of the model cannot be predicted with certainty. A stochastic model operates with the probability distributions of each element in the model and empirically determines just what will happen in a particular system by modeling the system under specific sets of conditions. By studying the responses which occur due to changing the controllable variables, the system can be optimized. The principal advantage of this class of model is that it may be used to solve many problems which cannot even be approached using conventional theoretical methods.

Deterministic Simulation. Deterministic simulation has been described by Hammersley and Handscomb (1) as an attempt to "exploit the strength of theoretical mathematics while avoiding its associated weakness by replacing theory by experiment whenever the former fails." Deterministic simulation is used to model processes which are governed at least in part by specific laws or rules and which will yield predictable results. For this reason, deterministic simulation has been used to simulate such activities as truck haulage (8), rail haulage (7), and the operation of bucket wheel excavators (14). In these applications, physical laws were used to determine accelerations, speeds, distances, power consumptions, etc., as a function of the operating characteristic curves for the equipment used. Normal practice in a model of this sort is to calculate the required variables at equal intervals of time in an interative fashion. At each iteration, the theoretical

laws can be used to calculate the desired variables, thus using the power of the digital computer to eliminate the necessity for extensive mathematical development. The model can be used to study an activity based on a theoretical basis and possibly optimize the activity by interpretting the outcome of the simulation experiments.

Deterministic simulators are sometimes further subdivided into event-oriented and time-oriented models. The time-oriented model is perhaps more widely used than the other and often is the easiest to program. In this type of model, a specific increment of time is chosen previous to each computer run. The program updates the simulation by that time increment and calculates all the variables of record at the new time. The calculations are repeated at each incrementation in the time variable. By using the proper logic, any variable can be accurately determined in the simulation if the concepts for simulating that variable are valid.

An event-oriented deterministic simulator is a simulator which does not update its time variable by a constant value but instead, updates the time variable only when specific predetermined events occur in the simulation. The events chosen to result in updating are generally the completion of activities after which decisions must be made.

The principal advantage of this method is that all the variables of record may not need updating during a particular time span. By using the knowledge about specific events in the process to be modeled, only those variables of record which require updating are calculated by the computer. A disadvantage of the method is that it may require more programming work than the time-oriented model for the same system. The choice between the emphasis on time increments or events will depend upon the system to be modeled. It may not be obvious which is the most advantageous before the program is initiated.

Choice of a Simulation Language

One of the first important tasks involved in constructing a computer model is the choice of a medium, i.e., a computer language, in which to write the model. There are numerous computer languages to choose from, including general languages and those specifically designed for application to simulation.

Several general simulation languages are available for use such as GPSS (General Purpose System Simulator) and SIMSCRIPT. These languages are designed to handle variations of standard simulation problems which are often encountered. GPSS, for example, is best suited to problems related to scheduling or to systems involving queueing while SIMSCRIPT is most applicable to inventory and similar problems. Several other languages are available which are designed to study situations of a more specific nature. DYNAMO and

SIMULATE are languages which are used to simulate economic systems. More complete descriptions of these programs can be obtained in the computer language manuals and in books on computer simulation (6).

One language which merits special attention here is GASP II. This is a FORTRAN-based language which is widely applicable and which has numerous advantages. The originators of the language outlined these advantages in their manual on GASP II (9). The most important advantages are related to GASP's base in a common computer language. As a result, the user does not have to learn a new language or obtain a new compiler for his present machine. Thus, two of the major problems related to using a simulation language are eliminated. In addition to these points, GASP is a versatile tool which will have appeal in many simulation analyses.

Another possible language for use in simulation is a general purpose language such as FORTRAN. While this language was not designed for specific use as a simulation language, it is widely used as such and has several advantages as a simulation language. The advantages that GASP II offers to simulation can also be obtained from FORTRAN. Thus, FORTRAN is advantageous since it is widely understood and does not require a special compiler. FORTRAN does present some problems for simulation. These include the lengthy input-output formatting and the lack of inherent debugging aids. However, these disadvantages will not be serious ones if the programmer is quite familiar with the

language and will not effect the program users.

With these facts in mind, the choice of FORTRAN was made for the simulation model being constructed. The main factors affecting this decision are its wide use and its ease of transfer from one machine to another. Most of the important simulation work done in the mining and construction industry has been performed by FORTRAN programs to date. In addition, nearly every digital computer has FORTRAN capability and this will enable the model to be used on the maximum number of computers. To further minimize transfer problems, the authors of the model have attempted to follow USA Standard FORTRAN IV as published by the United States of America Standards Institute (13). This will minimize the machine-dependent statements which will require changing when the program is used on other machines.

DESCRIPTION OF THE MODEL

The computer model presented here is a Monte Carlo type model written in the FORTRAN language using both deterministic and stochastic simulation methods to model the overall tunneling system. The program is written in an event-oriented manner with program updating being accomplished after specific jobs or events are completed. Most of the unit operation submodels are written in stochastic form although the materials handling subsystem contains much in the way of deterministic calculations. Emphasis has been placed upon supplying a number of options within the program to make the program applicable to various types or forms of rapid excavation systems. This portion of the report deals with the model objectives, the description of the simulation concepts, the logic used and the outline of program organization.

Model Objectives

The primary goal of this model is to simulate the common methods of driving a tunnel with a boring machine. To accomplish this goal, it is necessary to think in terms of a general computer program which contains a number of options which allow a user to vary the simulation of the unit operations and the way that they interact during the tunneling process. Primary attention is paid in this model to the materials handling process as this is one unit operation which promises to yield results from a systems evaluation. This conclusion is based upon observations about the

materials handling function creating a bottleneck in the operation (2,3,4,10) and due to the fact that more control may be exercised over the design and operation of the materials handling process than over the other unit operations. For this reason, the most significant programming time and attention was devoted to the modeling of the materials handling function.

To meet the basic objective of studying primarily the materials handling process, models for both cyclic and continuous handling methods have been provided so that either type may be studied. The cyclic systems have been programmed in a fashion which will allow either a track or a rubber-tired haulage system to be modeled providing that the characteristic curves of the driving mechanism are available. For continuous systems, similar accommodations have been provided so that either belt or hydraulic conveyors may be simulated.

Outline of Simulation Concepts Used

The outline of the logic and concepts used in the simulation model will deal first with the general principles or concepts used throughout the program. Afterwards, those concepts which apply primarily to the individual operations will be discussed. For purposes of outlining these specific concepts, the tunneling process will be divided into the following unit operations:

1) muck generation

2) materials handling

3) roof support

4) environmental control

Each of these unit operations will be discussed separately even though they may not be programmed in separate units in the program itself.

General Concepts. The first of the discussions on general concepts should perhaps be centered around the method of introducing the necessary probability functions into the program. For versatility and ease of input, all the probability functions which are used in the program are introduced as piecewise linear cumulative probability functions which are sometimes also referred to as cumulative frequency polygons or ogives (11). Figure 1 illustrates the method for reading the cumulative probability functions into the program. Several things should be mentioned here regarding these functions:

1) Neither the abscissa nor the ordinate values must be evenly spaced.

2) The first ordinate value, shown in Figure 1 as CP (1), must equal zero.

3) The final ordinate value, shown in Figure 1 as CP(NPOINT), must equal one.

4) The ordinate and abscissa values are read into the program as pairs and must be arranged in terms of increasing ordinate or cumulative probability values.

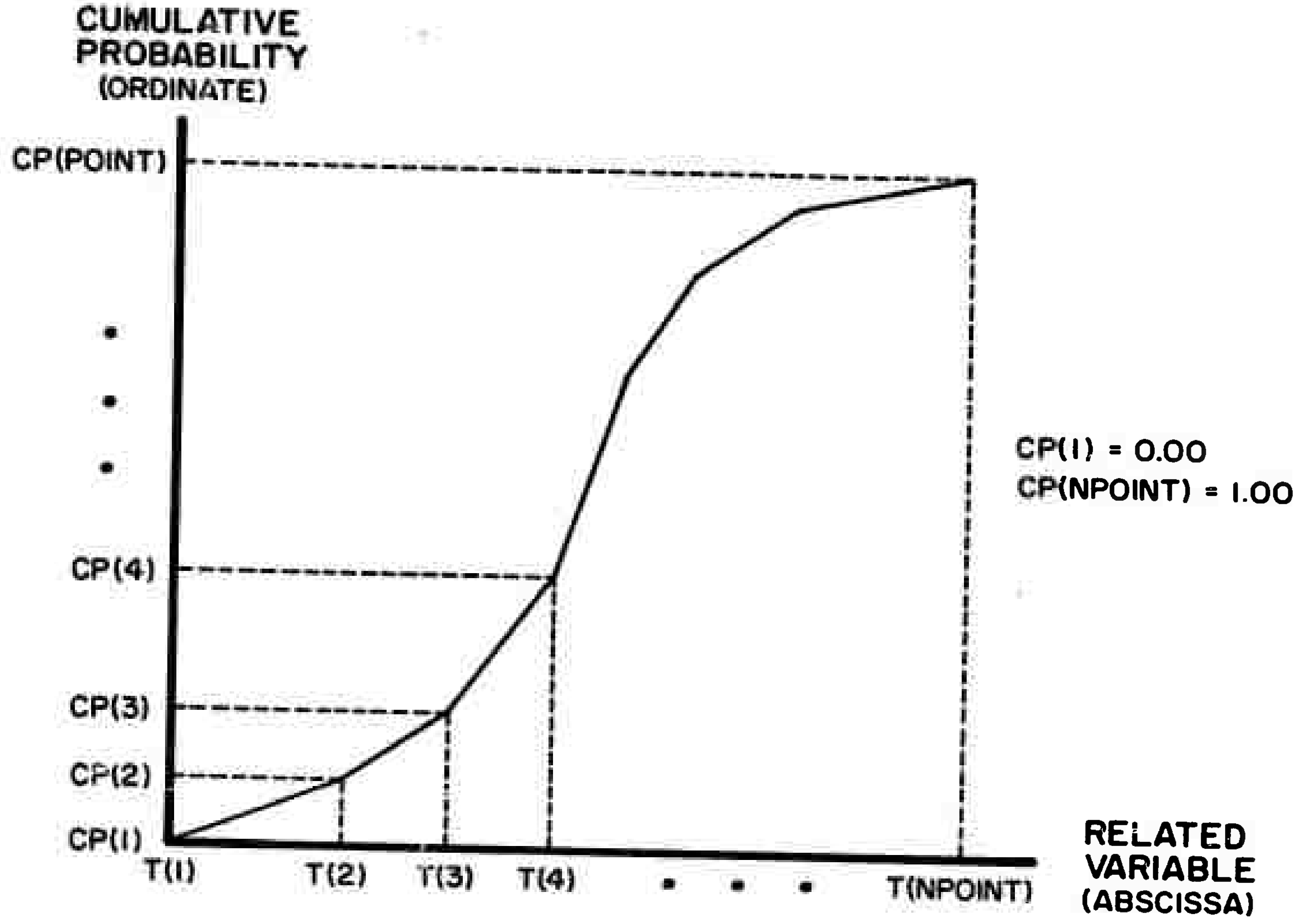


Figure 1 - Method of Introducing Probability Functions
Into the Computer Program

5) The number of abscissa and ordinate values read in may be up to 13. If more are necessary, the dimensions of the necessary variables may be easily changed to provide the additional storage space.

Should the user decide that a constant value is to be read into the program for a particular variable instead of a distribution of values, he may do so under the framework of the above method. The procedure that should be used is to read in two ordinate and abscissa values; the first ordinate value should be zero and the second should be one while both abscissa values should be equal to the constant desired for that variable. For example, if the user wished to read in a constant value of 10.5 for a specific variable, he would read in the following values for the cumulative frequency polygon:

CP(1) = 0.0 T(1) = 10.5

CP(2) = 1.0 T(2) = 10.5

The computer would then automatically assign a value of 10.5 to the variable in question every time it is called in the program.

Since the computer program described here is classified as an event-oriented model rather than a time-oriented model, a simplified explanation of an event-oriented model is presented to provide a basic background for users. The computer will store the clock time for all pertinent events in storage. In searching for the activity which should be updated next, the computer will go to the activity with the

shortest clock time. An example of how this would work is illustrated in Figure 2. In Figure 2(a), the status of the five activities assumed to exist in the problem are shown in Gantt chart fashion. The tick marks shown are indicative of specific events such as the completion of certain jobs or tasks. Since Activity 2 exhibits the shortest clock time, the computer must deal with or act upon Activity 2 before it proceeds to the activity with the next shortest clock time. If it is possible to update Activity 2 beyond its present clock time, then this is done as shown in Figure 2(b) and the computer then focuses attention on the new activity which has the shortest clock time, Activity 3.

If the situation requires that the updating of Activity 2 is restrained by another activity, then the start of another cycle of Activity 2 may not begin immediately. A very simple example is presented in Figure 2(c) where the start of Activity 2 is assumed to be restrained by Activity 3 (and only Activity 3). This type of situation may arise because of manpower, space, sequencing, or other limitations. In any case, in this situation Activity 2 must wait until Activity 3 is completed before it can be reinitiated. Thus, the wait is indicated by a dotted rather than a solid line. After Activity 3 is completed, Activity 2 is simulated to completion and Activity 3 then has the shortest clock time and is considered for updating next. In reality, the simulation of an activity may be restrained by numerous other activities of different types. However, the general

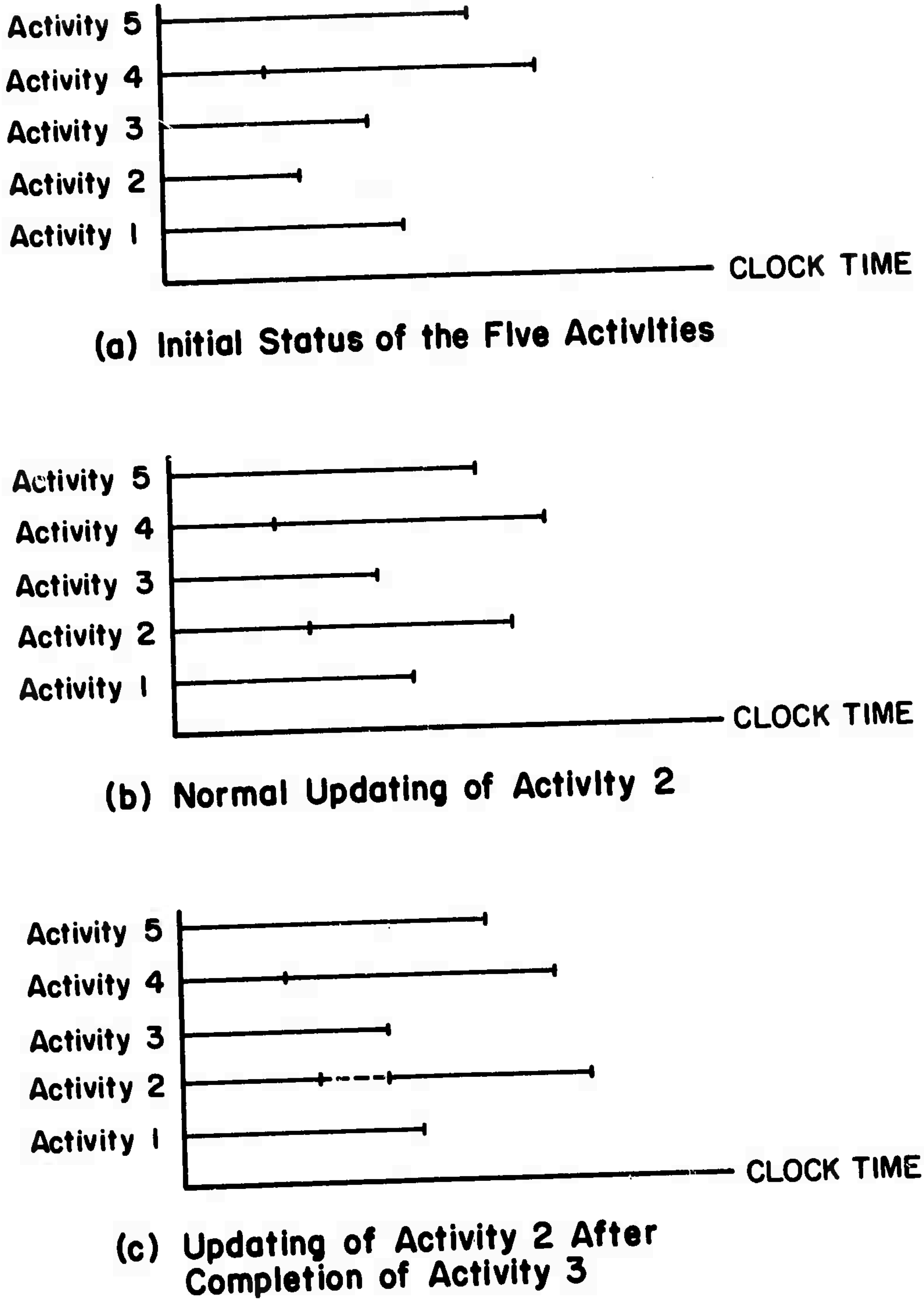


Figure 2 - Simple Examples of Updating in an Event-Oriented Simulation Model.

principle of focusing on the activity with the shortest clock time will apply no matter how complex the logic, providing that the model has been properly programmed.

The assignment and utilization of manpower is another consideration which applies throughout the computer model. The method of allocation of manpower was aimed at maximum versatility in the number of men assigned to a particular job. For each task in the tunneling process, an upper and lower limit on the number of workmen assigned is read into the program. The lower limit will reflect the minimum number of men required to safely carry out a task. The upper limit will generally be determined by space, productivity, safety, or other practical limitations of the activity. The computer program will always assign at least the minimum number of men to a job before it is initiated and will assign as many men as it can subject to availability and upper limit restrictions. As more men are assigned to a job, the time to accomplish the job is reduced proportionally. This policy is based upon the assumption that the upper and lower limits of manpower are reasonable and that all men are gainfully occupied on any particular job. As each job is completed, the men assigned to that job are reassigned to other jobs if it is possible. When several jobs require manpower simultaneously, the largest job in terms of manhours required is assigned men first.

On additional general topic of discussion here is the options available for outputting information from the computer. At the termination of each simulation run, a listing

of summary statistics is printed routinely. In order to allow users to determine just what is taking place in the computer program, a log of operations which outputs information on each significant event in the simulation as it occurs can also be optionally implemented. If the log of operations is not desirable or necessary, the user may suppress this series of output statements and the computer will print only the simulation summary statistics.

Muck Generation Subsystem. The muck generation subsystem includes all the activities taking place at the face of the tunnel concerned with the operation of the tunneling device. Thus, the muck generation subsystem is concerned primarily with the rate of advance, the inspection and repair and replacement of bits, and the repair and maintenance of the tunneling device. The bits are one of the most important of the considerations in the generation of muck, particularly in large tunnels driven in hard rock. Each bit on the face of the mole must be numbered for the purposes of the computer program. This can be done as shown in Figure 2 of a previous report (5) or in any other suitable manner. After numbering each bit, a time-to-failure probability function is assigned to each bit with the probability being expressed in terms of the feet of advance. In addition, another distribution for the replacement manhours required is assigned to each bit location in order to differentiate between bits in terms of the replacement time required. A separate time-to-failure and repair time

distribution is provided to similate repair work on the bits which does not require replacement, e.g., welding or other repair work on the bit housings. When a bit reaches the point of failure, it is not replaced immediately but is replaced at the first inspection after the failure has occurred, i.e., at the first opportunity for the failure to be discovered.

The inspection of the bits are assumed in the program to be completed in conjunction with the resetting of the jacks after completion of a normal stroke or on any occasion in which the machine is down for other purposes. It is assumed to be made normally after any integer number of cycles, i.e., after the jacks have been reset a predetermined number of times. If the bits are found to be in condition for more boring, the boring is reinitiated. If failed or worn bits are detected, the replacement operation is simulated before the boring is continued. Some tolerance, inputted in terms of feet of advance, is allowed in the program so that worn bits do not have to be replaced the instant their generated lifetime is assumed to end.

The muck generation subsystem also includes provision for repairs and maintenance which must be performed on the tunneling machine. Those repairs which result in the shutdown of the system are compiled into a time-to-failure distribution. A distribution of manhours required for these repairs is also provided to complete the simulation of this part of the process. In all cases of simulating repairs

associated with the mole, the tunneling machine is assumed to be down in the model and as many crewmen as possible under the circumstances are assigned to the repair action in order to expedite the boring operation. All of the above processes are simulated in a relatively straightforward stochastic manner. This is accomplished by placing each event (bit failure, mole failure, etc.) in an event matrix and testing at each update time to see if any action is required. In this manner, all events in the muck generation subsystem are handled in the same matrix and are scanned at the same time in the program.

The final important element in this subsystem is the rate of generation of muck during the operation of the mole. This process is accomplished in the program through the advance rate distribution and the geometry of the face. The advance rate potential of the tunneling device in feet per hour can be formed into a probability distribution. A random sample from this distribution is chosen to obtain an advance rate which applies for the advance of one stroke length of the machine. This advance rate is then combined with the tunnel cross-section to determine the muck flow rate. An instantaneous advance rate would have been more precise but the result in terms of the simulation would have been negligible, i.e., the long-term production of the machine does not appear to be sensitive to this variable. In the computer program, the simulation of the muck generation subsystem is carried out in the main program and in SUBROUTINE MUCK.

Materials Handling Subsystem. The materials handling subsystem was the most complex portion of the overall model to program. This situation existed as a result of the emphasis placed upon the materials handling process in the model and the physical complexity of some of the muck handling systems. Simulation of both cyclic and continuous systems have been provided for in the model. The computer model is designed in such a manner that the haulage distance is increased as the tunnel is advanced. This is accomplished by keeping track of the advance and increasing the haulage length each time a predetermined advance, DELTH, is attained. This also results in changes in the inby end of the haulage system which must be reflected within the model.

(1) Cyclic Systems. Materials handling using cyclic systems are the most complex methods from a systems standpoint. The cyclic materials handling systems were modeled primarily with single-track haulage systems in mind but a haulage system using rubber-tired vehicles can be accommodated using the same model since the simulation program is designed with this in mind. The initial concern of the cyclic materials handling model to be discussed here is the method of introducing the tunnel grade characteristics into the program. This is accomplished by dividing the tunnel into sections with each section having a constant grade. In case of a tunnel with continuously varying grade, the tunnel profile may have to be approximated by the assumed linear grade segments. The segments are read into the program

in order proceeding from the dumping point and continuing to the face of the tunnel as shown in Figure 3 where a tunnel profile with five sections is illustrated. In all cases, the distances are measured along the center line of the tunnel and changes in azimuth are ignored and assumed to be of little or no consequence in the movement of the haulage devices as they traverse the tunnel. For programming reasons, the sections outside the portal are counted separately from the sections within the tunnel. The program will accommodate a tunnel profile with 100 sections without alteration.

The switches, or switchpoints in the case of rubber-tired vehicles, are assumed to be evenly spaced along the tunnel route. For rubber-tired vehicles, a bored tunnel is not an ideal roadbed and thus it is not usually possible for the vehicles to pass anywhere except where special passing points have been blasted out of the tunnel. For this reason, the simulation model is assumed to be able to model this type of haulage system with passing points at equal intervals along the tunnel. The cyclic materials handling submodel simulates the movement of the vehicles on a switch-to-switch basis in SUBROUTINE TRANS. For example, assume that a train is waiting on the inbound side of Switch B of Figure 4 on one of its empty trips to the face of the tunnel. When the track is cleared, SUBROUTINE TRANS controls the movement of the empty train by calling SUBROUTINE MOTION which simulates the motion of the train from Switch B to Switch A. In order to obtain clearance to use the section

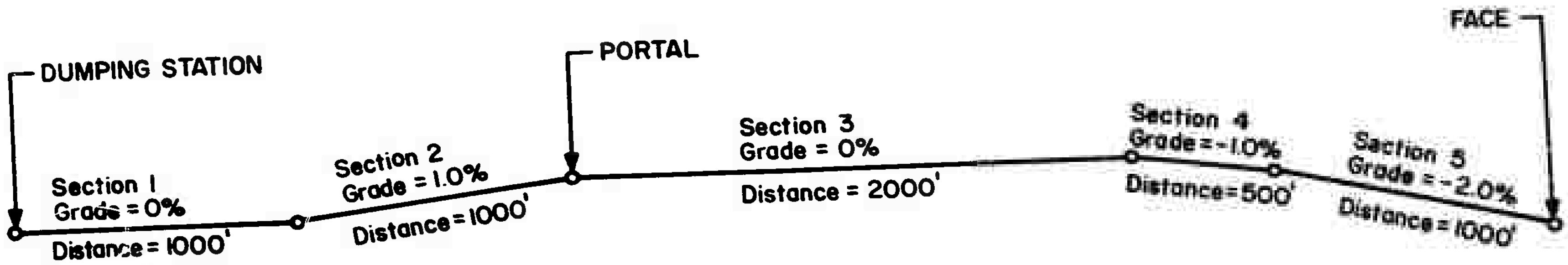


Figure 3 - Method of Representing the Tunnel Profile

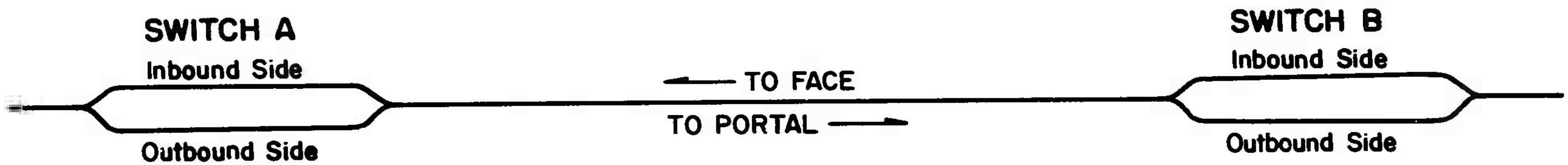


Figure 4 - Diagram of Two Adjacent Switches

of track between the two switches, the track section must be clear and the empty train must have priority as determined by the decision or control function in SUBROUTINE TRANS. The decision as to which train has priority to a particular section of track is made on a first-in-first-out basis. Adjacent switches, such as Switch A and Switch B, are always considered together in determining this priority. For example, if an inbound train reaches Switch B before an outbound train reaches Switch A, then the inbound train has the priority for the use of the connecting track and it completes its movement to Switch A before the outbound train can initiate its move from Switch A to Switch B. By considering all the switches simultaneously, SUBROUTINE TRANS can control the operation of all the trains in an event-oriented fashion while SUBROUTINE MOTION simulates the actual switch-to-switch movements.

SUBROUTINE MOTION handles the motion of the train in an event-oriented deterministic fashion based upon the physical laws of motion. One of the first publications dealing with this basic simulation method for haulage systems was introduced by Nelson (7). For this application, his basic deterministic approach has been changed to one which does not make use of equal time increments but instead concentrates upon specific events in the movement of the train as its travel is simulated. The basic physical law used is Newton's second law of motion which for the case of a rolling vehicle (12) can be written as:

$$a = \frac{(T - F_f - F_g)G}{W_\ell + W_c + W_m}$$

where: T = tractive effort of the driving wheels in pounds

F_f = force required to overcome friction in pounds

F_g = force required to overcome the gravity component in pounds

W_ℓ = weight of the locomotive in pounds

W_c = weight of the cars in pounds

W_m = weight of the muck in pounds

a = acceleration in feet per second per second

g = acceleration of gravity, 32.2 feet per second per second

Since the tractive effort does not remain constant for changes in the speed of the tractive unit, some method of applying the formula above must be used so that the changes in the speed and the tractive effort are reflected in the program. To accomplish this, the characteristic curve of the tractive unit which relates its speed and tractive effort must be made available for use in the computer model. A number of selected points along this characteristic curve are read into the computer program as shown in Figure 5 for a hypothetical two-speed locomotive unit. The program then assumes that the characteristic curve is linear between succeeding points so that the effect is an approximation of the actual curve by a piecewise linear function defined by the points selected for input. The degree of simulation

accuracy required in the runs will dictate the number and spacing of the points selected. At present, the proper variables in the computer program are dimensioned to allow reading in up to 30 points along this characteristic curve.

The use of the tractive effort-speed curve in SUBROUTINE MOTION is carried out on an iterative basis using certain specified events to indicate the need for recalculation of the variables of motion. Normally this is done based upon the assumed linear segments of the characteristic curve as follows. A train (or other vehicle) which is starting from rest is assumed to do so at the average tractive effort value for the first assumed linear segment along the curve in Figure 5, i.e., at a tractive effort value of [TE(1)+TE(2)]/2. An acceleration is calculated based upon this tractive effort and the train moves until the acceleration results in the train achieving the speed at the end of the first linear segment, S(2). When this occurs, a new average tractive effort value, [TE(2)+TE(3)]/2, is applied for the period of time required for the train's speed to reach S(3), and so on. This iterative method continues until the train reaches its maximum allowable speed or until it reaches a new grade section in the tunnel. At the maximum speed, the train's speed is not permitted to accelerate any further and it continues with a constant velocity. When a change in grade occurs, this changes the gravity force component and thus the acceleration is automatically recalculated within the program even though the

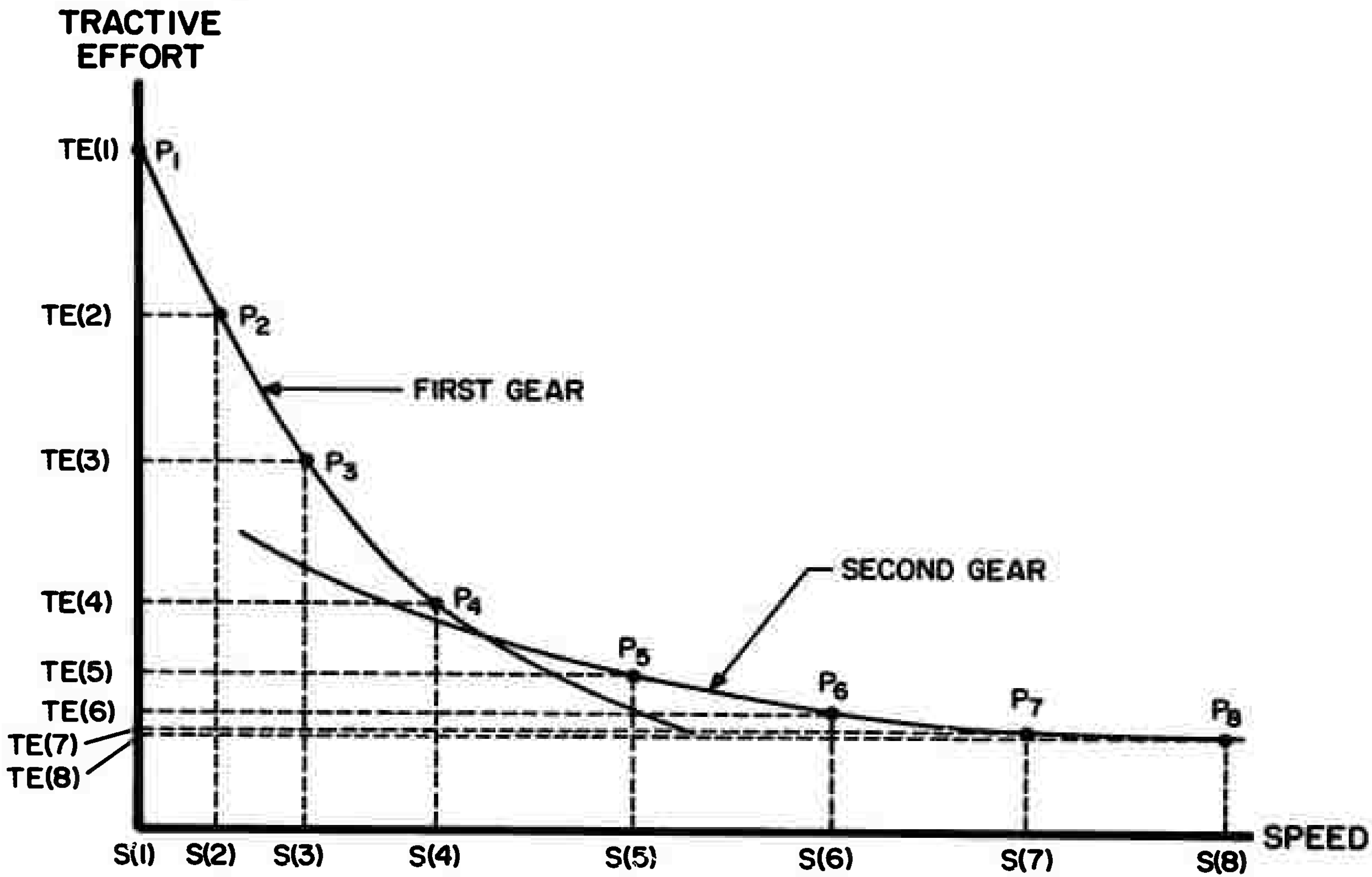


Figure 5 - Method of Inputting Data From the Characteristic

train has not speeded up to the next input point on the tractive effort-speed curve. To perform this calculation, the computer will interpolate to determine the current value of the tractive effort and average this value with the next higher tractive effort value read in along the curve. This average will then be used to calculate the initial acceleration on the new grade. It is assumed in this method that the mass of the train is a point mass located at the locomotive unit. This assumption will not effect the simulation significantly unless the tunnel profile is changing rapidly and considerably in grade, a situation which does not occur in rapid excavation tunneling jobs.

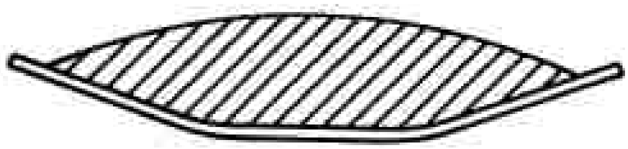
The dumping, loading, and switchout times for the cyclic materials handling systems are handled separately. The loading times are determined by the interaction of the muck generation and the materials handling systems. The cars of a train are loaded by the action of the mole as it advances into the face. Thus, the loading time for each car is a stochastic function which is dependent on the rate of advance which is generated in the program for the tunneling device. The dumping time of each train is also determined stochastically to allow for the variations which will certainly occur in the process. Thus, a dumping time cumulative probability function must be read into the computer as illustrated in Figure 1. The switchout time mentioned above is the name given here to

the time required for an empty and a loaded train to switch out under the gantry conveyor using the switch normally located directly behind the conveyor. This process may be deterministically simulated under ideal circumstances. However, operators often use incoming trips to haul the tunnel supplies and these must be unloaded when the train reaches the face area. Thus, it is necessary to use a probabilistic approach on the switch-out time in order to reflect the variations in time due to the necessity of unloading the supplies at the face. This can be done by utilizing a bimodal distribution, the first or shortest mode reflecting switchout times where no supplies are unloaded and the second mode related to times necessary to complete the switchout operation when the unloading time is included in the switchout time. When unloading of supplies is not a problem, a unimodal distribution may be suitable for this variable.

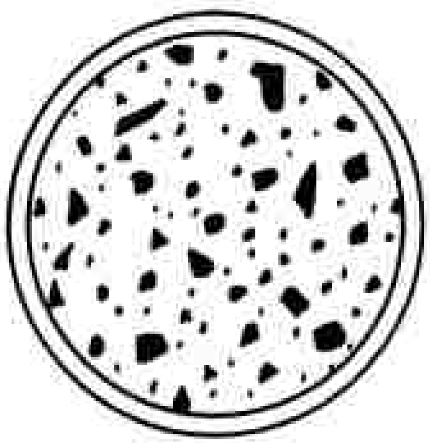
At the start of a simulation run, the trains are positioned behind the tunneling device in such a manner that they are spaced one switch apart. This setup places the trains in as favorable a state of readiness as can be achieved in the tunnel. This initial setup scheme was chosen since it was felt that the trains would be in a ready state during a normal startup of a tunneling operation, e.g., at the beginning of the first shift of the simulation.

(2) Continuous Systems. The simulation of a continuous materials handling system is simple in comparison with the cyclic systems. To model the actual transport of the muck, the concept of effective cross-section is defined as the area occupied by the broken muck in a cross-section of the material flow when the materials handling method is operating at its maximum capacity. The value would be a constant for any system and would be independent of the flow velocity and the material density. The effective cross-section for a belt conveyor and those for a hydraulic or pneumatic system would differ as shown in Figure 6. In all cases, however, when the effective cross-section is multiplied by the velocity of transport and the proper density value, the result should be the maximum mass flow rate of the muck for the specific materials handling system used. Care should be taken in expressing the value of the density as the effective cross-section of the belt is based upon the profile of broken rock while those for the systems using pipe are based upon solid material. Once the muck has entered the flowstream, the actual transport can be easily simulated. This can be modeled deterministically based upon the flow velocity and the length of the haulage system.

One of the most important considerations in the materials handling subsystem for continuous systems is



THE EFFECTIVE CROSS-SECTION OF A CONVEYOR IS THE CROSS-SECTIONAL AREA OF THE MUCK WHEN THE CONVEYOR IS OPERATING AT ITS MAXIMUM CAPACITY (INDICATED BY THE CROSS-HATCHED AREA ABOVE)



THE EFFECTIVE CROSS-SECTION OF A HYDRAULIC OR PNEUMATIC CONVEYOR IS THE CROSS-SECTIONAL AREA OCCUPIED BY THE MUCK WHEN THE CONVEYOR IS OPERATING AT ITS MAXIMUM CAPACITY (INDICATED BY THE SHADED AREA ABOVE)

Figure 6 - Illustration of the Effective Cross-Section for Continuous Materials Handling Systems

the interaction with the muck generation subsystem. The primary function is to regulate the flow of muck into the materials handling subsystem. If the muck generation rate is greater than that which can be handled by the materials handling subsystem, then the rate of muck generation is slowed to permit the materials handling subsystem to accommodate the muck. This would, of course, slow the advance of the overall system. When the materials handling device can handle the flow of muck, the muck generation subsystem can then be allowed to operate in an unconstrained manner.

At the other end of the materials handling subsystem where the muck is dumped, another possibility for interruptions in the flow of muck occurs. This can arise because of an interaction with another transport system, because of the condition of a holding device, or due to numerous other factors which can effect the flow of material from the tunnel. Because of the varied nature of the possibilities which may be encountered on this end, no specific delay has been programmed. However, if a specific type of delay is expected to occur at the discharge point of the continuous materials handling system, this can be added to the model in the manner which will correctly affect the simulation of this characteristic of the system.

<u>Tunnel Support Subsystem</u>. The support function for tunneling is quite variable because of the nature of the

geologic materials through which tunnels are driven. Many excavations are provided with support in a fashion which may be considered to be cyclic, i.e., a cycle of jobs is carried out to advance the support by one "set." In the computer program, the simulation of such a cyclic method is carried out by assigning a probability distribution to the number of manhours required to advance the support through a single cycle of support work. This makes the interrelationship between the muck generation and the support subsystems an easy one to handle in the model. The time to advance the tunneling device the length of one set can be compared to the time required to complete one cycle of support and tunnel advance can be limited to the speed of the slower process. This procedure will permit the support subsystem to keep up and provide the support which is required to safely advance the tunnel.

Other methods of providing support in a tunnel are much less cyclic in nature and vary significantly from the methods suggested above. Examples of this type of support methods include roofbolting and guniting. For methods which are not cyclic in nature, the simulation must be handled differently. This can be done, however, within the framework of the cyclic support methods outlined above by shortening the length of a "set" to a value which is short compared to the stroke of the tunneling machine. In this manner the simulation will approach the installation of support which occurs continuously rather than one which causes the support to be advanced

in spurts. As an illustration, the action of installing roof bolts may be modeled by inputting the probabilistic number of manhours required to advance the support a relatively short distance along the tunnel e.g., one foot. As the support is advanced, the advance of the mole can be checked to insure that it does not exceed the advance of the available support exactly as was done for the cyclic systems. Since the support is not advanced in long increments, however, the model is realistic in relation to the actual system.

Environmental Control Subsystem. The primary tasks in providing an adequate environment throughout the tunnel normally involve extension of the ventilation system and maintaining a water supply if used on the cutting head to aid in dust abatement. The process of supplying these auxiliary needs will normally be performed at specific intervals of tunnel advance. The installation of the ventilation tubing is normally undertaken at intervals of advance equal to the length of the tubing sections. The simulation of the installation is performed stochastically by providing a probability function for the number of manhours required to install one length of the ventilation tubing. Provision has been made for allowing the tunnel to advance by more than one length of the tubing before the installation of the tubing must be undertaken. A similar method is applied to the process of maintaining the supply of water at the face. A

separate probability distribution for the demands of this system is read into the computer for each run.

Additional auxiliary services may be necessary at the face which may or may not be directly related to the environmental control function. These may include such functions as the advancing of the track, the extension of the sump lines, or other jobs which must be carried out on a periodic basis. These processes may be simulated within the environmental control subsystem just as those functions directly connected to the environment in the tunnel. A third periodic process of this type can be simulated by using the probability distribution already provided within this subsystem. Other functions of a similar nature can be handled if necessary by providing additional distributions and using the framework of logic inherent in the environmental control subsystem.

TESTING OF THE MODEL

The testing of the computer model was only partially completed at the end of the project year. The initial testing phase concerned with checking the logic of the program and its macro behavior was accomplished using data obtained mainly in the field. However, more exhaustive evaluation and development was scheduled for the second year of the project and is yet to be undertaken.

Data Collection

In the testing of the computer program, as much data as possible from the field was used to supply the computer program. In the muck generation subsystem, data obtained through the courtesy of the White Pine Copper Company was used in the simulation. The bit life distributions were compiled from actual bit records kept by the mine personnel during the period of experience with their Robbins machine. The bit lives available were formed into a histogram for each bit on the head of the machine. The histograms were formed from the raw data and then converted into cumulative frequency diagrams by a computer program written for that purpose. The repair times for each of the bits were not determined from actual data but were instead estimated by company officials. The repair times for each of the bits on the machine were individually assumed to be constant values but higher constant repair times were assigned to

bits near the periphery of the cutting head where working conditions were more difficult due to space restrictions. The time-to-failure and repair distributions for the tunneling device were determined by reconstructing the operating record from shift reports and obtaining the individual times between failure and the number of manhours required to complete each repair. These were then formed by computer into the necessary distributions for use in the computer program.

The data for testing of the cyclic materials handling subsystem was not hard to gather, although actual field data was not available for some of the variables. A tunnel profile with many grade changes was hypothesized for use in the test. Trains corresponding to present practice were assembled for the simulation. Three two-speed diesel locomotives with a weight of fifteen tons were selected. Eight fifteen-ton cars with an empty weight of three tons were chosen for each train. The distribution of the weight loaded in each of the trains was assumed to be normal with a standard deviation equal to 5% of the mean value. A bimodal switchout time distribution was hypothesized to indicate a practice of unloading supplies from the incoming trains. The distribution of dumping time was estimated from one contractor's experience on a previous tunneling project.

Data for the tunnel support and the environmental control subsystems was obtained from available records on the White Pine system. The individual samples were collected by studying the shift reports and extrapolating as best as

possible the number of manhours spent during specific activities involving each of the subsystems. By collecting information on a large number of occurrences, distributions of the manhours required for specific advances of these two subsystems were formed.

Testing Procedure

The initial test of the program was made with the idea of eliminating the programming problems in the model, i.e., eliminating the bugs and errors in logic in the model. This was accomplished simply by attempting to run the program and check the validity of the results. The most complex portion of the program was the materials handling subsystem and this subsystem was the most difficult to debug. When the obvious debugging problems were out of the way, the program was then checked to be certain it was operating logically and outputting data in the log of operations which agreed with calculations made by hand. This procedure probably did not result in testing all the possible branches of the program even though an attempt was made to cover as much of the logic as possible. After several problems were eliminated, the program seemed to be at least superficially correct and free of obvious bugs.

No attempt was made to test the accuracy of the simulation model in terms of the overall results as this step in the testing procedure was planned for the second year of the project. The testing of the accuracy of the model was to be

undertaken using the data obtained at White Pine as input to a simulation run which would model the tunneling operation for about one month's time. The results of the simulation in terms of the tunnel advance and the times spent in the various unit operations would then be compared with the actual values of these variables obtained from tunneling records for the time period in question. Attempts could then be made to adjust or improve the computer program in areas where its performance was concluded to be unsuitable.

Present Status of the Program

Since the development of the program is not complete at the present time, users should recognize that parts of the model may still be in rather unfinished form in the program. In particular, the program may still contain bugs which have not been detected. In addition, options which would make the program more versatile and useful may not be included due to the limited period of use of the model. As an example, it was hoped to expand the program to include the logic for systems using both cyclic and continuous materials handling systems, the cyclic system being applied to the handling of supplies while the continuous system was applied to the handling of muck. Such logic does not presently exist in the model. These inadequacies are to be taken care of during the latter stages of development and use of the program. At present, however, the program is still in a state of

development and testing and should not be considered a finished product.

One of the most important aspects of the testing of the model which has not been completed is the testing of the accuracy of the program in modeling actual tunneling situations. For this reason, the fact that the model will complete a run and output data is not sufficient reason to have complete confidence in the results. Inaccuracies may be caused by bugs in the program or by the assumptions of the model not being valid for all or some of the conditions under which the model is to be applied. Users should note these warnings before making use of the program.

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APPENDIX A

USERS' GUIDE TO THE COMPUTER PROGRAM

Definition of Important Variables in the Program

This section contains the definition of the most important variables and the units in which they are expressed in their usage in the program. The variables which must be input into the program are also defined in this list. To prepare an input data deck, a user must refer to the main program and SUBROUTINE TRANS where all the data is input. The data prepared for the main program should appear first in the data deck while the data for SUBROUTINE TRANS follows. All the input variables are defined in this list, which is alphabetized for convenience in locating specific variable names. Users may refer to the program for the order and format information on variables and then to this list for the definition.

ACCFC -- available accelerating force, tons

ACCMAX -- maximum acceleration rate allowed in the tunnel, feet per second per second

ACCR -- acceleration rate of a train, feet per second per second

ACT(I) -- the reduced time to complete activity _i_ after redistributing the manpower.

ACTIM(I) -- the time required to complete the _i_th activity

ADRT -- the tunnel advance rate, feet per hour

AFT -- feet of advance required to load one train

AVAMH -- manhours available for the support function

AVATF -- available tractive effort of a locomotive at its current speed, pounds

BINSMH -- manhours required to inspect the bits and regrip the mole

CAPMH -- the capacity of the continuous materials handling system, tons per minute

CCTM -- the time in minutes required to generate one trainload of muck

CF(I,J) -- the jth ordinate value read in from the ith cumulative probability curve in the main program

I = 1 to NBITS correspond to the probability distributions for the time-to-failure of the bits in feet or operating hours.
I = NBITS + 1 to 2*NBITS correspond to the probability distributions for the manhours required to replace the bits
I = 2*NBITS + 1 corresponds to the probability distribution for the time between bit repairs, hours
I = 2*NBITS + 2 corresponds to the probability distribution for the time between mole repairs, hours
I = 2*NBITS + 3 corresponds to the probability distribution for the time between repairs of the third (optional) equipment, hours
I = 2*NBITS + 4 corresponds to the probability distribution for the advance rate, feet per hour
I = 2*NBITS + 5 corresponds to the probability distribution for the manhours for repair of the bits
I = 2*NBITS + 6 corresponds to the probability distribution for the manhours required for repair of the mole
I = 2*NBITS + 7 corresponds to the probability distribution for the manhours required to repair of the third (optional) equipment
Altogether, 2*NBITS + 7 probability distributions are read into the main program.

CFD(I) -- the ith ordinate value read in from the cumulative probability curve for the dumping time

CFL(I) -- the ith ordinate value read in from the cumulative probability curve for weight of the muck in a car

CFR(I) -- the ith value of the cumulative probability read from the support requirement function

CFS(I) -- the ith ordinate value read in from the cumulative probability curve for switching time

CROSEC -- cross-sectional area of the tunnel, square feet

CT(I) -- the ith abscissa value read in from the cumulative probability curve for dumping time, minutes

CTIME -- clock time from the start of the simulation, minutes

CTLOC(I) -- total or clock time of the _i_th locomotive in minutes

CTM(I) -- the _i_th value of the ACT(I) array if arranged in ascending order

D1 -- the distance in feet from one stop to the next stop of a train excluding the distance required to stop

D2 -- distance in feet to the end of the present grade section

D(I) -- horizontal length of section _i_ of the tunnel profile in feet

DECEL -- maximum deceleration rate allowed in the tunnel, feet per second per second

DELTH -- increment added to the tunnel length as the face advances, feet

DISTR(I) -- distance traveled by the _i_th locomotive in feet

DISW -- distance between two switching points in feet

DMS -- current distance between the switch closest the face and the next switching point, feet

DS(I) -- distance from the dumping station to the _i_th switch

DSTOP(I) -- distance required for the _i_th locomotive to stop, feet

FCAR -- the friction coefficient of each mine car in pounds per ton

FLOCO(I) -- friction coefficient of locomotive _i_ in pounds per ton

FRFC -- force required to overcome the frictional resistance, pounds

FTA(I) -- the _i_th abscissa value read from the support requirement curve, manhours per foot of advance

G(I) -- present grade of section _i_ of the tunnel profile

GAMMA -- specific weight of the muck in the solid, pounds per cubic foot

GFC -- force required to overcome the grade resistance, pounds

GLEFT -- distance in feet remaining to be traveled in the track section

HAUL -- the current haulage length in feet

HRPSH -- working hours per shift, i.e., the total shift time minus travel and other idle time

ICYCLE -- the variable which indicates the type of material handling system
ICYCLE = 0 indicates a continuous system

IDE(I) -- queueing number of the ith locomotive while waiting empty at the dumping station to enter the tunnel; IDE(I) = 0 means the ith locomotive is not in the queue

IDEOS -- the variable which indicates that the simulation is to terminate; IDEOS = 1 indicates the termination

IDL(I) -- queuing number of the ith locomotive as it waits to dump its muck at the dumping station; IDL(I) = 0 means the ith locomotive is not in the queue

IDLOAD -- indicates whether any trains were loaded or not; IDLOAD = 1 indicates trains have been loaded

IL -- the number of the locomotive which has the shortest clock time but which is awaiting the movement of another locomotive

ILC -- the number of the locomotive which has the same clock time as that of the main program

ILS -- controls the input statements in SUBROUTINE TRANS; ILS = 0 means no simulation is performed

ILWTID -- the variable which indicates the beginning of the simulation; ILWTID = 1 indicates the beginning

IMAN -- number of men currently available

INLC -- the number of the loaded locomotive at the loading point

INSPM -- the number of men required to inspect the bits

IR -- the subscript used to obtain the repair manhours for ITEM

ITEM -- the number of the unit which has the shortest life

KK -- the next lower speed point on the characteristic curve

KMAX -- number of points on the characteristic curves of the locomotive at which input data will be read

KOUNT -- the number of bits which need to be replaced

LC(I) -- the queuing number of the trains in the ILC list

LCLAS -- number of points read in from the cumulation frequency function for the weight of muck in one muck car

LIL -- the variable which retains the numbers of the locomotives which were in the previous IL list

LL(I) -- the switch on which the ith locomotive is located

LLW(I) -- the number of the locomotive in the ith spot in the LIL queue

LOAD(I) -- indicates the status of the ith train
LOAD(I) = 0 indicates the train is empty
LOAD(I) = 1 indicates the train is loaded

LOGPRT -- print option variable
LOGPRT = 0 indicates that the complete log of operations is printed
LOGPRT ≠ 0 indicates that only the summary of the simulation is printed

LS(I) -- the variable which indicates the status of the ith switch
LS(I) = 0 indicates the switch is empty
LS(I) = 1 indicates the switch contains an empty train
LS(I) = 2 indicates the switch contains a loaded train
LS(I) = 3 indicates the switch contains both an empty and a loaded train

LW(I) -- the number of the ith locomotive in the clock time queue

LWTID -- indicates whether or not there is an empty train at the loading point; LWTID = 0 indicates no empty train

MAD -- number of men available to be reassigned when a repair activity is completed

MAN(I,J) -- the variable which stores the upper and lower limits on the number of men assigned to each activity
I = 1 corresponds to the lower limit
I = 2 corresponds to the upper limit
J = 1 to NBITS corresponds to the limits of manpower for the replacement of the bits
J = NBITS + 1 corresponds to the limits of manpower for the repair of the bits
J = NBITS + 2 corresponds to the limits of manpower for the repair of the mole
J = NBITS + 3 corresponds to the limits of manpower for the repair of the third (optional) equipment

MANAW(I) -- the number of men assigned to the ith job

MAXSHT -- maximum number of shifts that the simulation is to be run

MH -- variable which indicates which option was employed in reading in the muck generation cumulative frequency curves
MH = 0 indicates the abscissa values are in terms of hours
MH ≠ 0 indicates the values are in terms of the feet of advance

MM -- grade section number which train NL is presently traversing

ML -- number of the locomotive currently being moved

MNBITL -- lower limit on the number of men required to repair bits

MNBITU -- upper limit on the number of men required to repair bits

MOTM -- the time in minutes required for the hauling of the muck generated by TEMSTR

MREST -- cumulative number of men who spent idle time during the computer run

MSS(I) -- number of the locomotive occupying the ith switch

MTB -- number of men who are reassigned when a repair activity is completed

NACF -- the number of events to be simulated in the muck generation subsystem in addition to the events related to bit replacement

NBITS -- the number of bits

NCARS -- number of muck cars assigned to each train

NCF -- total number of cumulative frequency diagrams read into the muck generation subsystem

NCLAS(I) -- the number of points read in for the ith cumulative probability function of the muck generation subsystem

THIRD1 -- cumulative time spent in doing the third event, minutes

NCREW -- the number of men in the crew

NDC -- number of points read in from the cumulative frequency function for the dumping time

NEVENT -- the number of separate repair activities currently being performed

NL -- locomotive number presently being simulated

NLDL -- number of loaded trains waiting at the dumping station to dump

NLDE -- number of empty trains at the dumping station

NLDL -- the number of loaded trains at the dumping point

NLOCO -- number of locomotives

NRBG -- the number of points read in from the cumulative probability curve for the support function

NS -- the switch from which locomotive NL is moved

NCS -- number of points read in from the cumulative frequency function for the time to switch trains behind the mole

NSCF -- the number of time-between-repair cumulative probability functions read into the muck generation subsystem

NSDP -- number of sections of the haulage profile between the dumping point and the tunnel mouth read into the program

NSECS -- number of sections of the haulage profile within the tunnel read into the program (after input, NSECS is the number of sections in the tunnel profile at the time of simulation)

NSW -- number of switching points currently in the haulage system

NSHIFT -- the number of shifts simulated so far in the current run

OTRD -- distance in feet that the train overtravels

PWT -- the time the continuous materials handling system can operate before a breakdown, minutes

RADIUS -- radius of the tunnel, feet

REQMH -- required manhours of support work for one foot of advance

REQTF -- required tractive effort, pounds

RESTMH -- cumulative number of idle manhours

S(I,J) -- speed of the ith locomotive at the jth point on its characteristic curve

SAFT -- cumulative length of advance since the last value of DELTH was added to HAUL

SCCTM -- the cumulative time in minutes to advance by TEMSTR

SGL(I) -- distance in feet from the _i_th switch to the inby end of the track section on which the switch exists

SLEFT -- distance in feet to the next switch point

SP -- former speed of the train, feet per second

SPEED(I) -- velocity of the _i_th locomotive, feet per minute

SSCC -- incremental time in minutes that a train waits for the completion of another event

ST(I) -- the _i_th abscissa value read in from the cumulative probability curve for switching time, minutes

STROKE -- stroke of the mole, feet

SWTTIM -- the cumulative delay time in minutes due to the support subsystem

T(I,J) -- tractive effort of the _i_th locomotive at the _j_th point on its characteristic curve

T1 -- the time in seconds required to travel the distance D1

T2 -- time in seconds to reach the end of the present grade section

TBELT1 -- operating time of the continuous materials handling system, minutes

TBELT2 -- delay time due to the continuous materials handling system, minutes

TBELT3 -- downtime of the continuous materials handling system, minutes

TBIT1 -- cumulative working time of the bits, minutes

TBIT2 -- cumulative idle time of the bits, minutes

TBIT3 -- cumulative time the bits are under repair, minutes

TBIT4 -- cumulative time the bits are under replacement, minutes

TBIT5 -- cumulative time the bits are under inspection, minutes

TDUMP(I) -- dumping time in minutes of the _i_th locomotive during the last dumping cycle

TEMPWT -- the weight in tons of the portion of the material remaining to be loaded in the current train

TEMSTR -- portion of the stroke which remains to be completed

TFT -- the number of feet the mole can advance before being stopped

TFTA -- the incremental number of feet the mole is to be advanced

THIRD1 -- time the third (extra) subsystem spends working, minutes

THIRD2 -- time the third (extra) subsystem spends in waiting, minutes

THIRD3 -- time the third (extra) sybsystem undergoes repair, minutes

TIMAX -- maximum clock time in minutes that the simulation is to be run

TIME(I) -- time required in minutes for the ith locomotive to get from one switch to the next minus the value of TPASS(I) or TSTOP(I)

TLOAD(I) -- loading time in minutes of the ith locomotive when it was last loaded, minutes

TLOC1(I) -- cumulative time the ith locomotive spends in the loading process, minutes

TLOC2(I) -- cumulative time the ith locomotive spends in the dumping process, minutes

TLOC3(I) -- cumulative time the ith locomotive spends in motion, minutes

TLOC4(I) -- cumulative time the ith locomotive spends waiting, minutes

TMH -- manhours required to advance by TFTA

TMOLE1 -- cumulative working time of the mole, minutes

TMOLE2 -- cumulative idle time of the mole, minutes

TMOLE3 -- cumulative time the mole is under repair, minutes

TNL -- maximum length of advance of the tunnel in feet for the simulation run

TOLIT -- the tolerance placed upon the repair starting times in minutes; i.e., when one repair action is initiated, the potential repairs are checked and are also initiated if they are within the tolerance time of requiring repair

TPASS(I) -- time required for the ith locomotive to travel through a switch without stopping, minutes

TPM -- the muck generation rate in tons per minute

TSEC -- the current length of the ith section which has been driven and added to the variable HAUL

TSTOP(I) -- time required for the ith locomotive to decelerate and stop on a switch, minutes

TSUPPT -- cumulative time expended for support activities, minutes

TSW -- the time in minutes required to switch out the loaded train at the loading point

TTM -- the time in minutes that the mole can advance before being stopped

TUNNEL -- the length of tunnel bored to the present, in feet from the portal

TV(I,J) -- the jth time or other abscissa value read in from the ith cumulative probability curve in the main program in units of feet or operating hours (for a definition of the meanings of each of the values of I, see the variable CF(I,J))

VELMAX -- maximum velocity allowed in the tunnel, feet per second

WAITIM -- cumulative idle time of the muck generation subsystem in minutes

WTCAR -- weight in tons of each muck car while empty

WTD -- cumulative weight of muck dumped, tons

WTG -- cumulative weight of muck generated, tons

WTIM -- the time in minutes to move an empty train to the loading point

WTL(I) -- the ith abscissa value read in from the cumulative probability curve for weight of muck in a car, tons

WTLDG -- the weight in tons of the load to be generated by TFTA

WTLOAD(I) -- weight of the muck in the ith train in tons

WTLOC(I) -- weight of locomotive i in tons

WTMUCK -- the weight of muck in tons to be loaded in one train

WTTRN(I) -- weight in tons of the ith locomotive and its empty cars

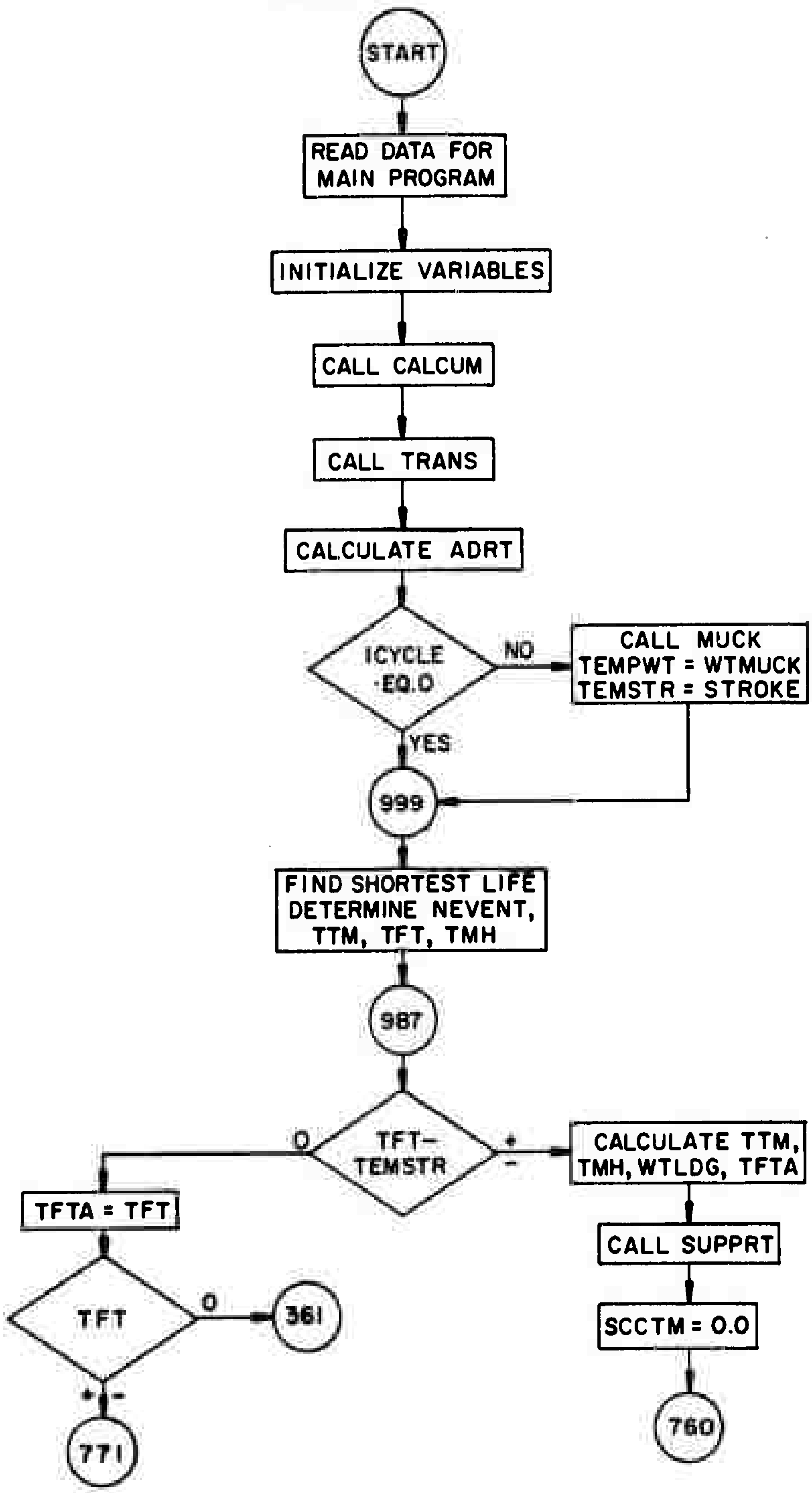
WWTM --incremental time in minutes that a train waits for the completion of another event

XX(I) -- the abscissa value as determined from SUBROUTINE CALCUM

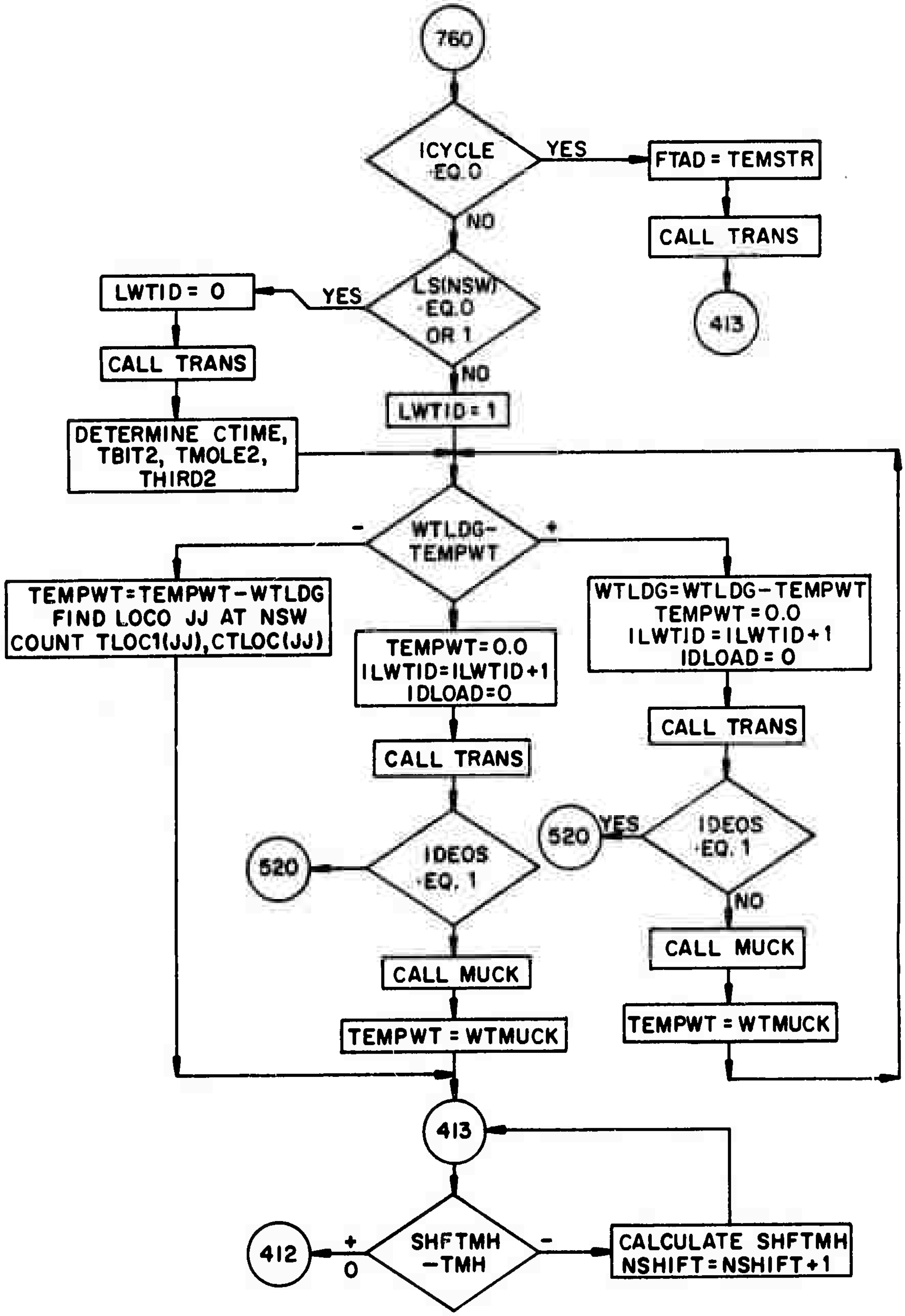
Computer Logic Diagrams

The Computer logic diagrams of the main program and two of the seven subrotines, SUBROUTINE MOTION and SUBROUTINE TRANS, appear on the following pages. The remainder of the subroutines are not represented in this section since they perform relatively simple functions for which the logic diagrams were considered unnecessary. The diagrams presented are not intended to be a detailed flowchart of all the calculations and manipulations that take place in the computer program. Instead, they are meant to convey the macro logic of the simulation and way that it fits together in the model. Most of the variables which appear in the logic diagram are identified in the previous section of this Appendix. In the logic diagrams, two types of offpage connectors are used. The connectors appear as small circles with numbers or letters enclosed. Connectors containing numbers indicate the actual program statement at which the connection is to be made. This gives the reader one extra bit of help in following the program using the logic diagram. The connectors containing letters are those for which no exact statement number to which the program proceeds could be named.

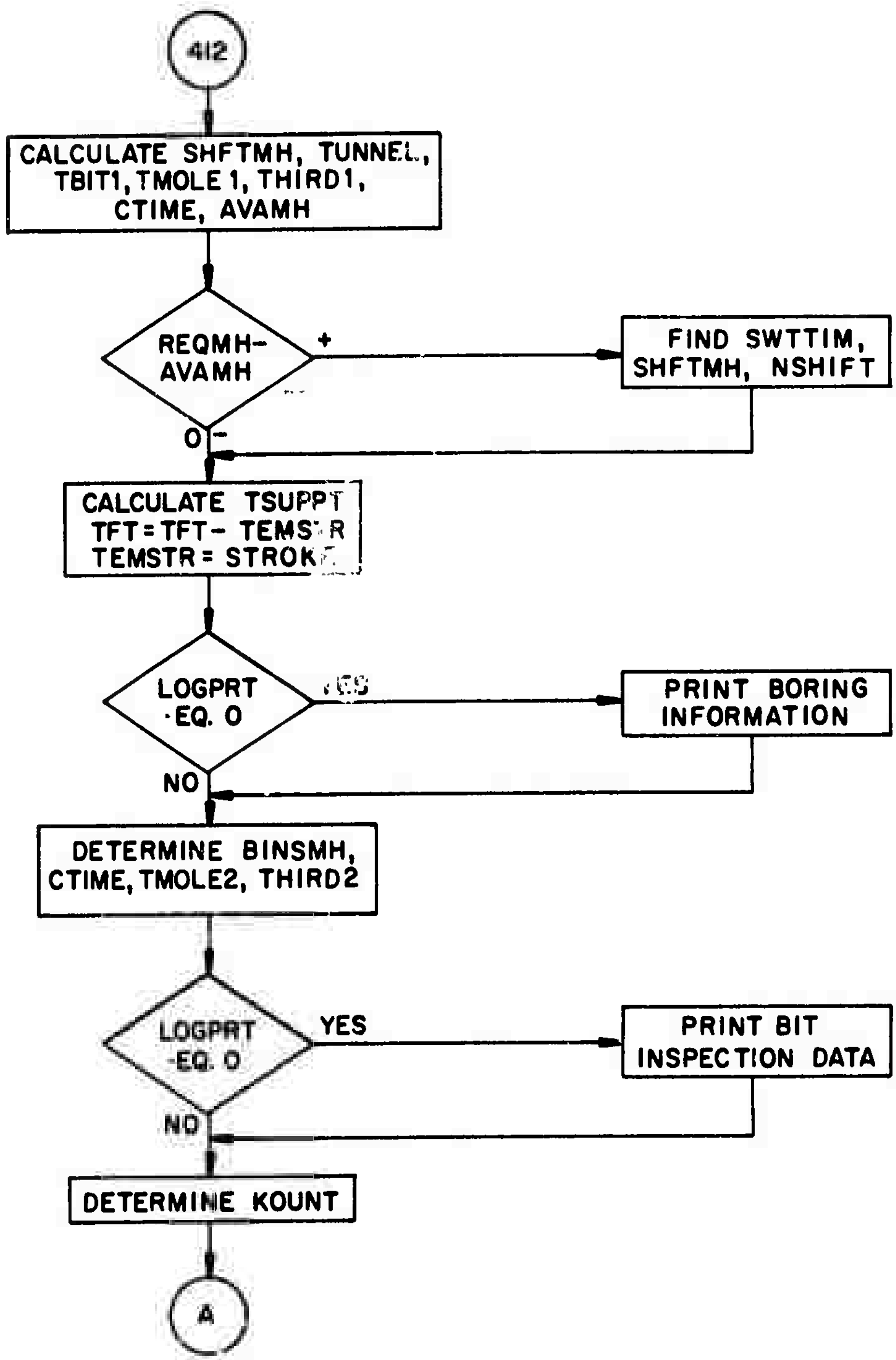
MAIN PROGRAM



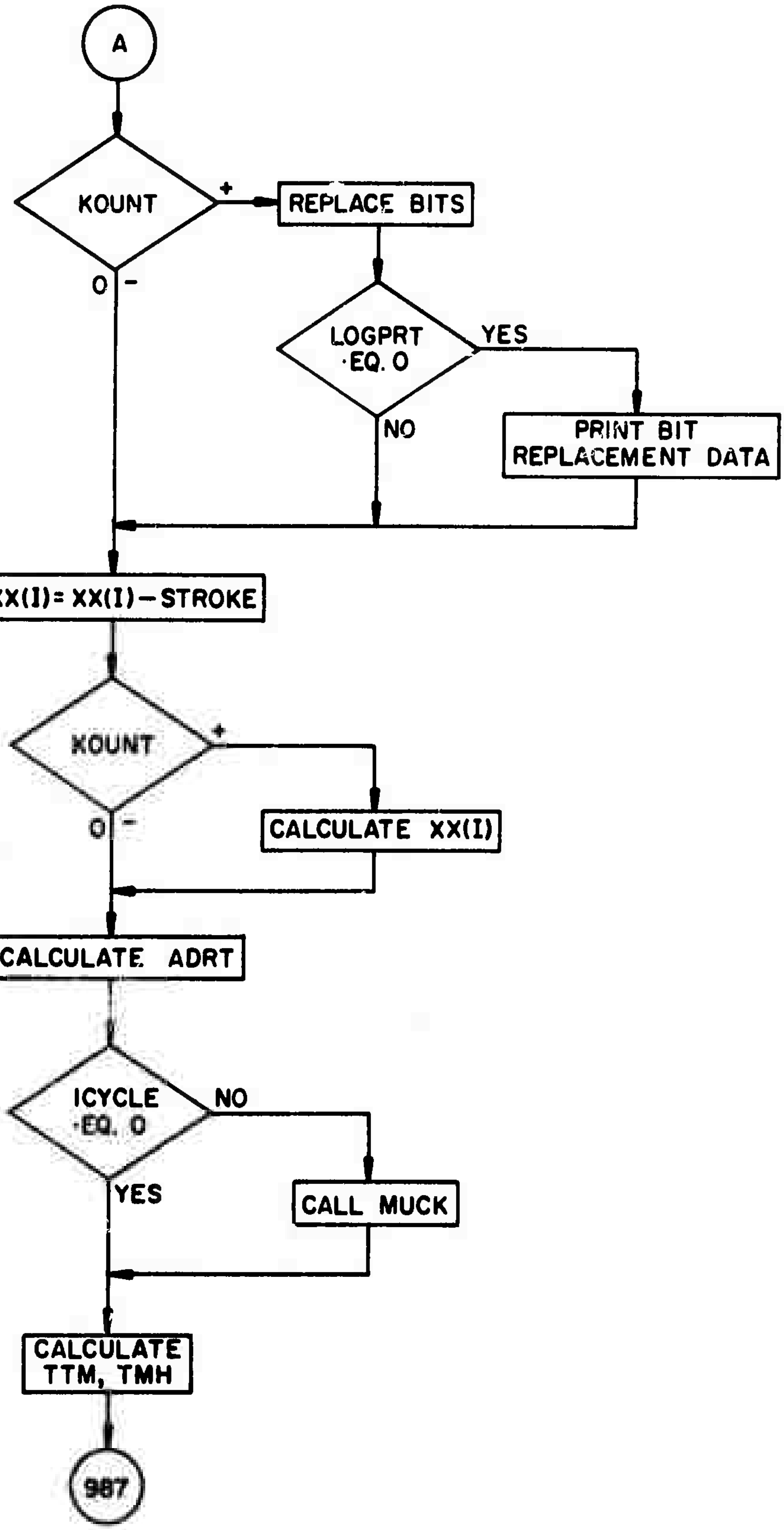
MAIN PROGRAM (CONT'D)



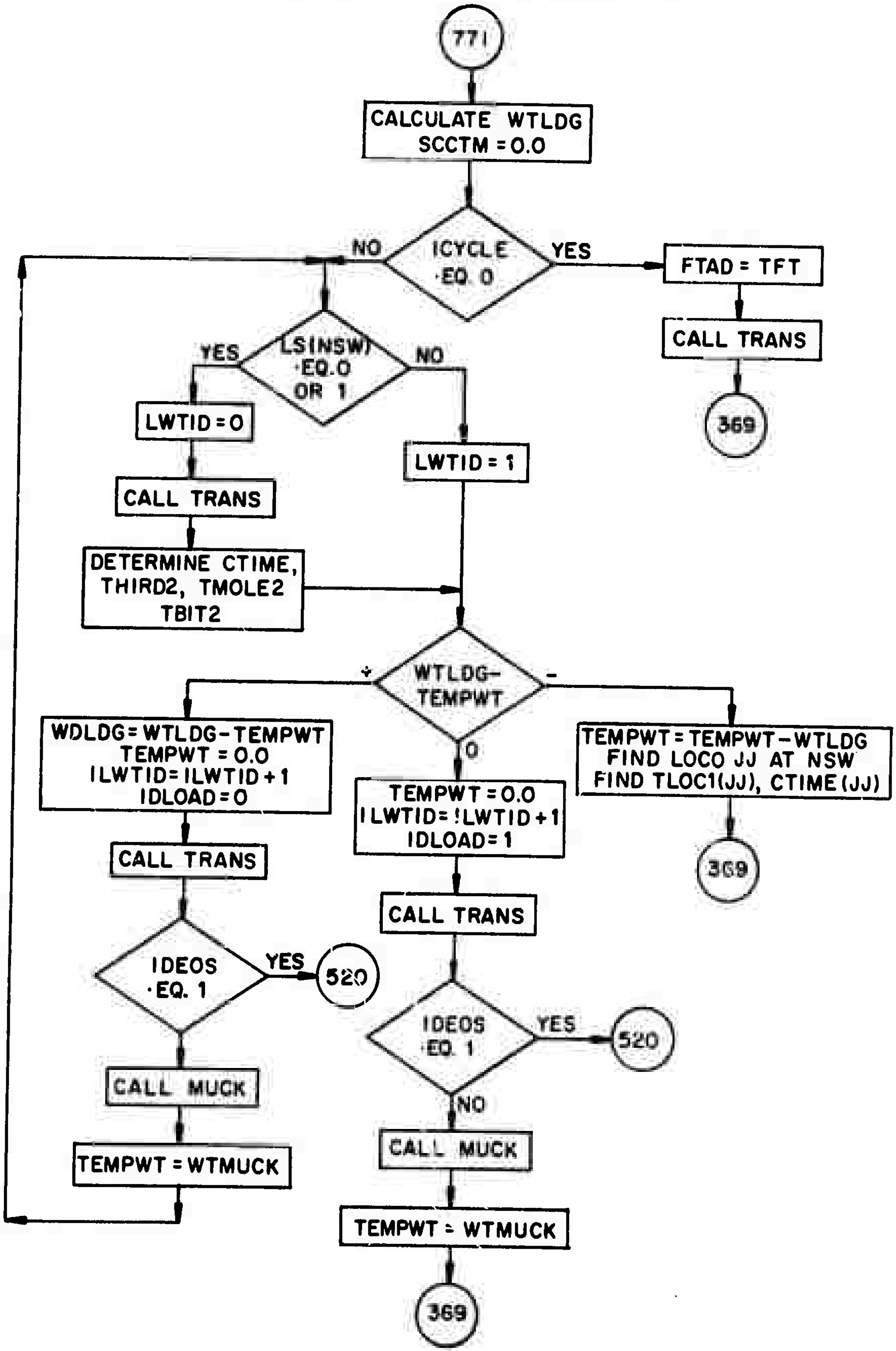
MAIN PROGRAM (CONT'D)



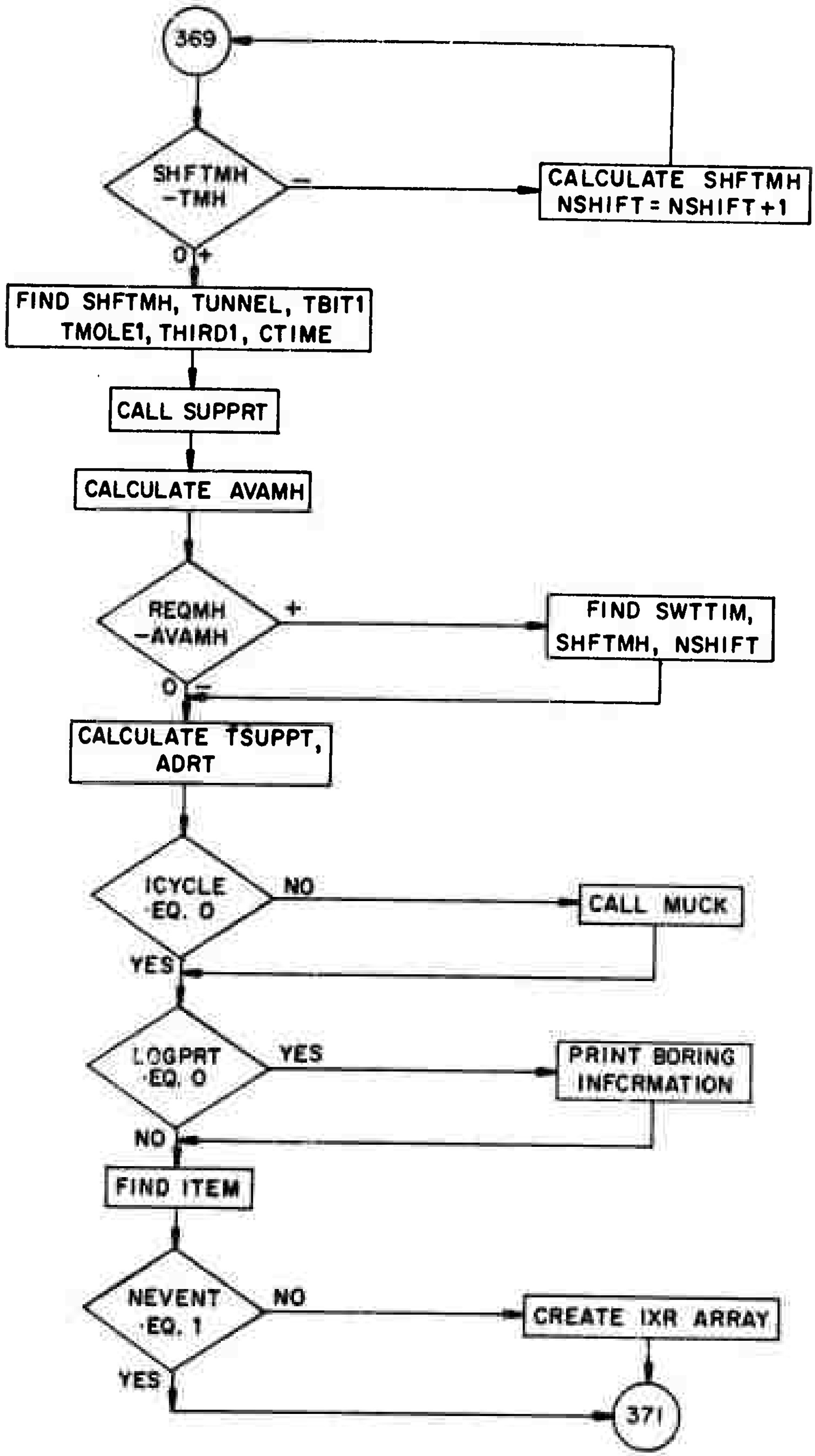
MAIN PROGRAM (CONT'D)



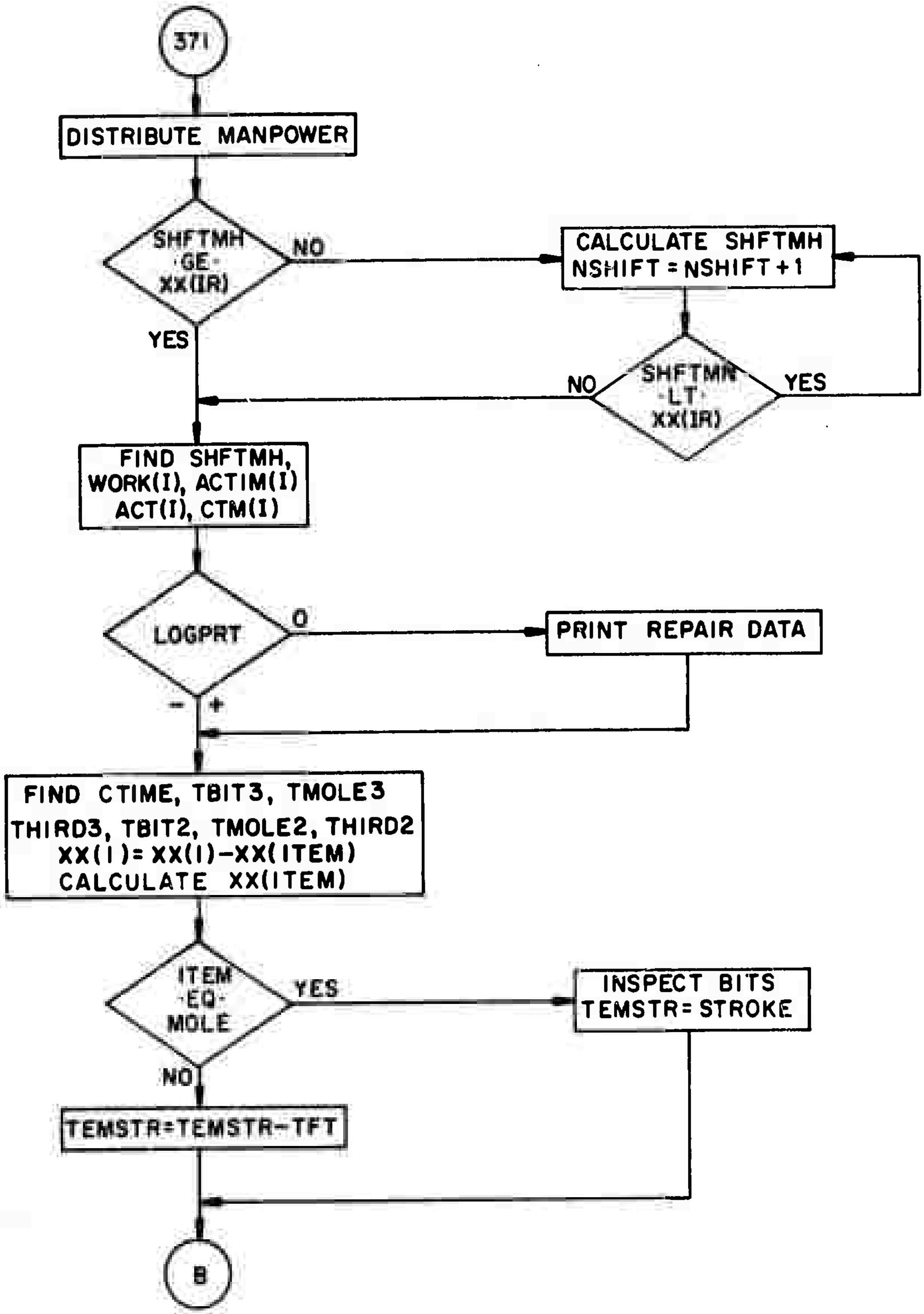
MAIN PROGRAM (CONT'D)



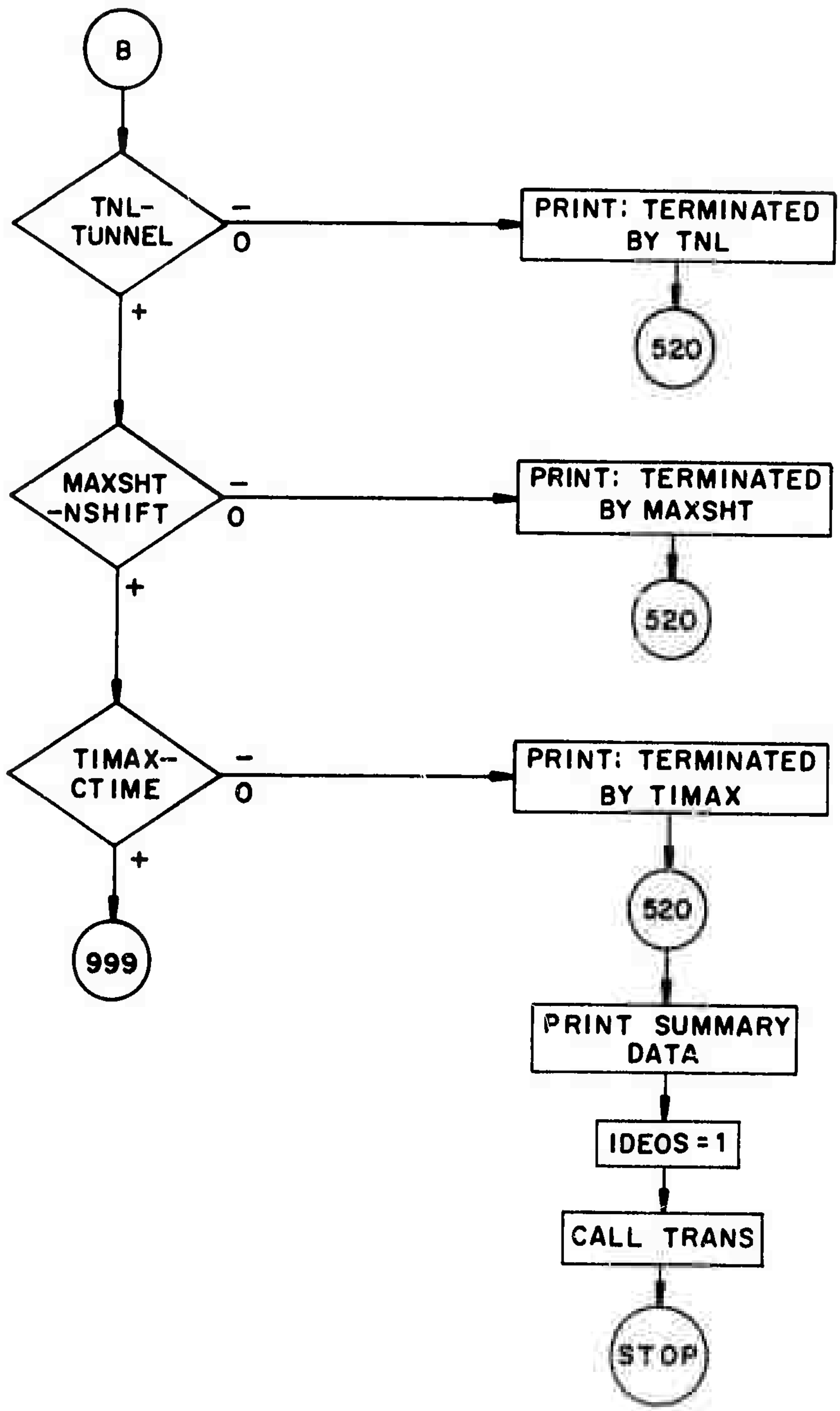
MAIN PROGRAM (CONT'D)



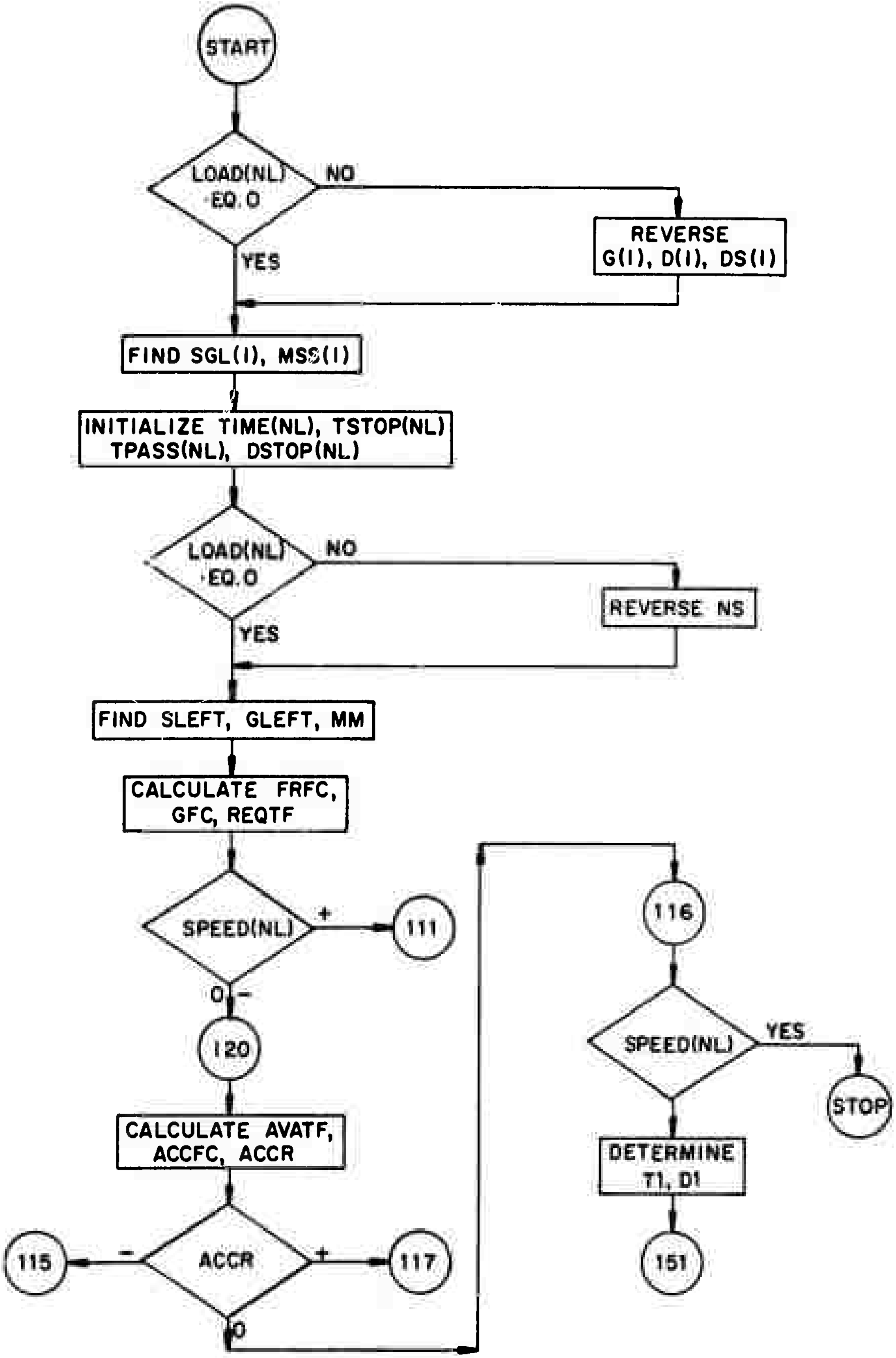
MAIN PROGRAM (CONT'D)



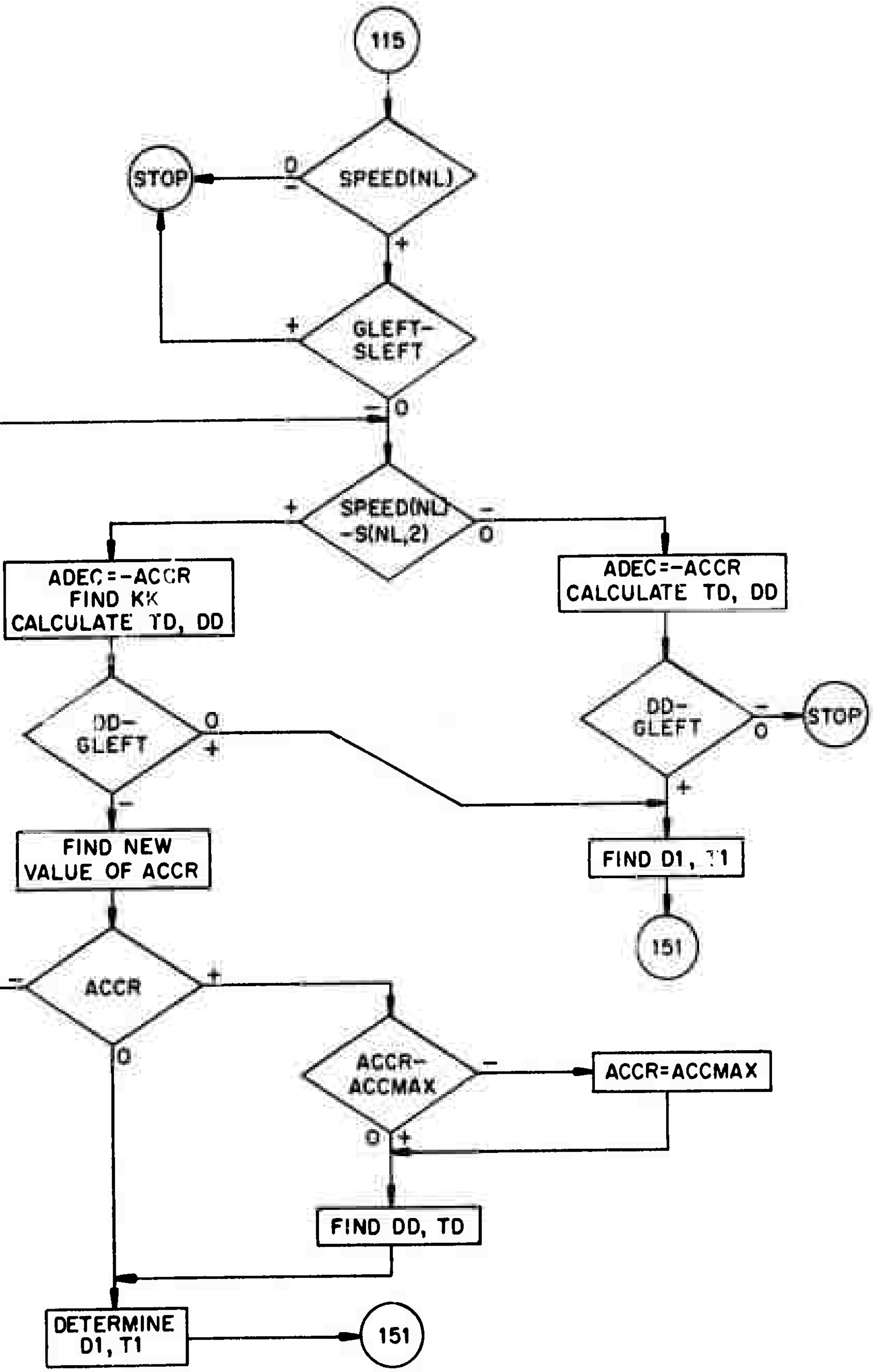
MAIN PROGRAM (CONT'D)



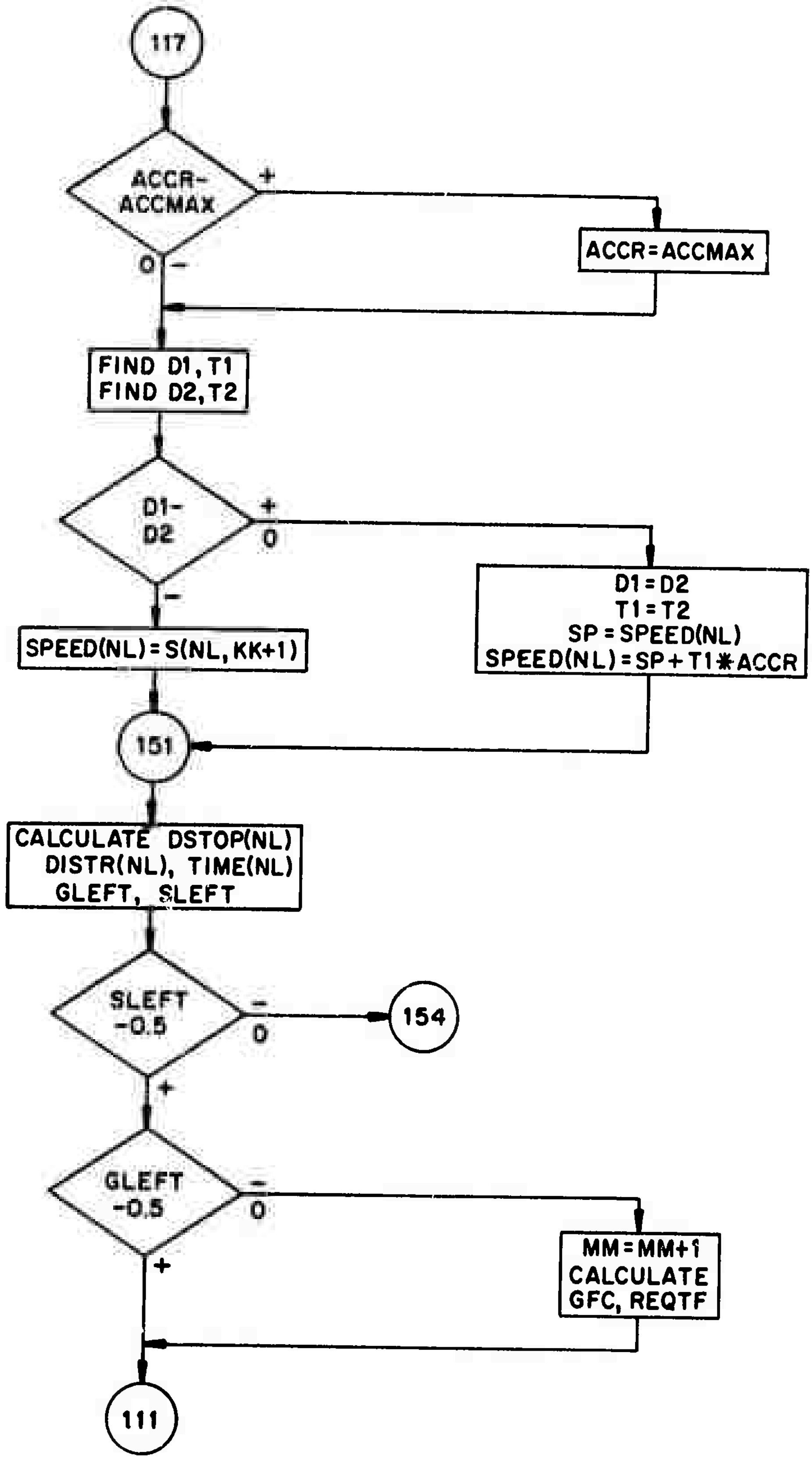
SUBROUTINE MOTION



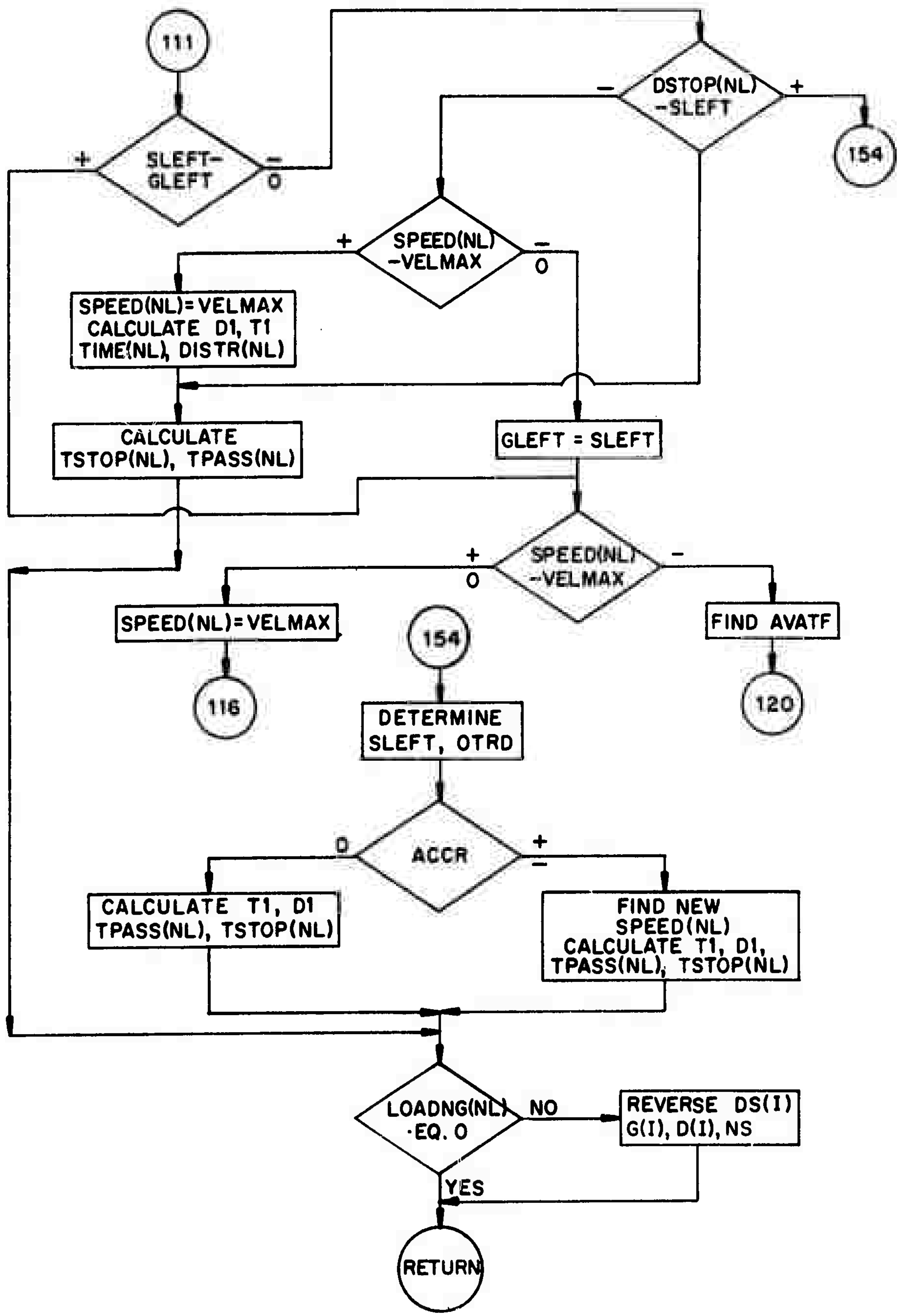
SUBROUTINE MOTION (CONT'D)



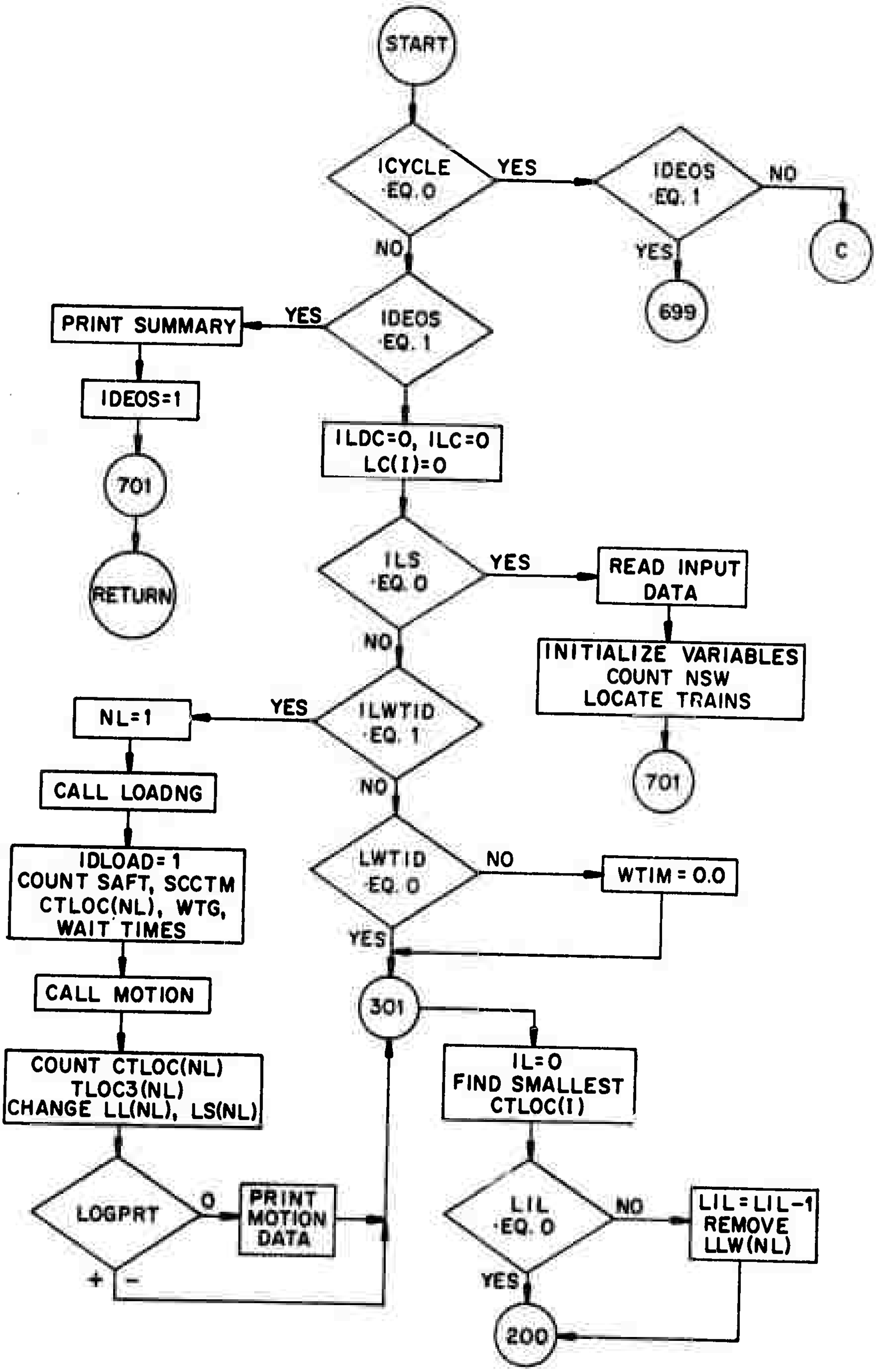
SUBROUTINE MOTION (CONT'D)



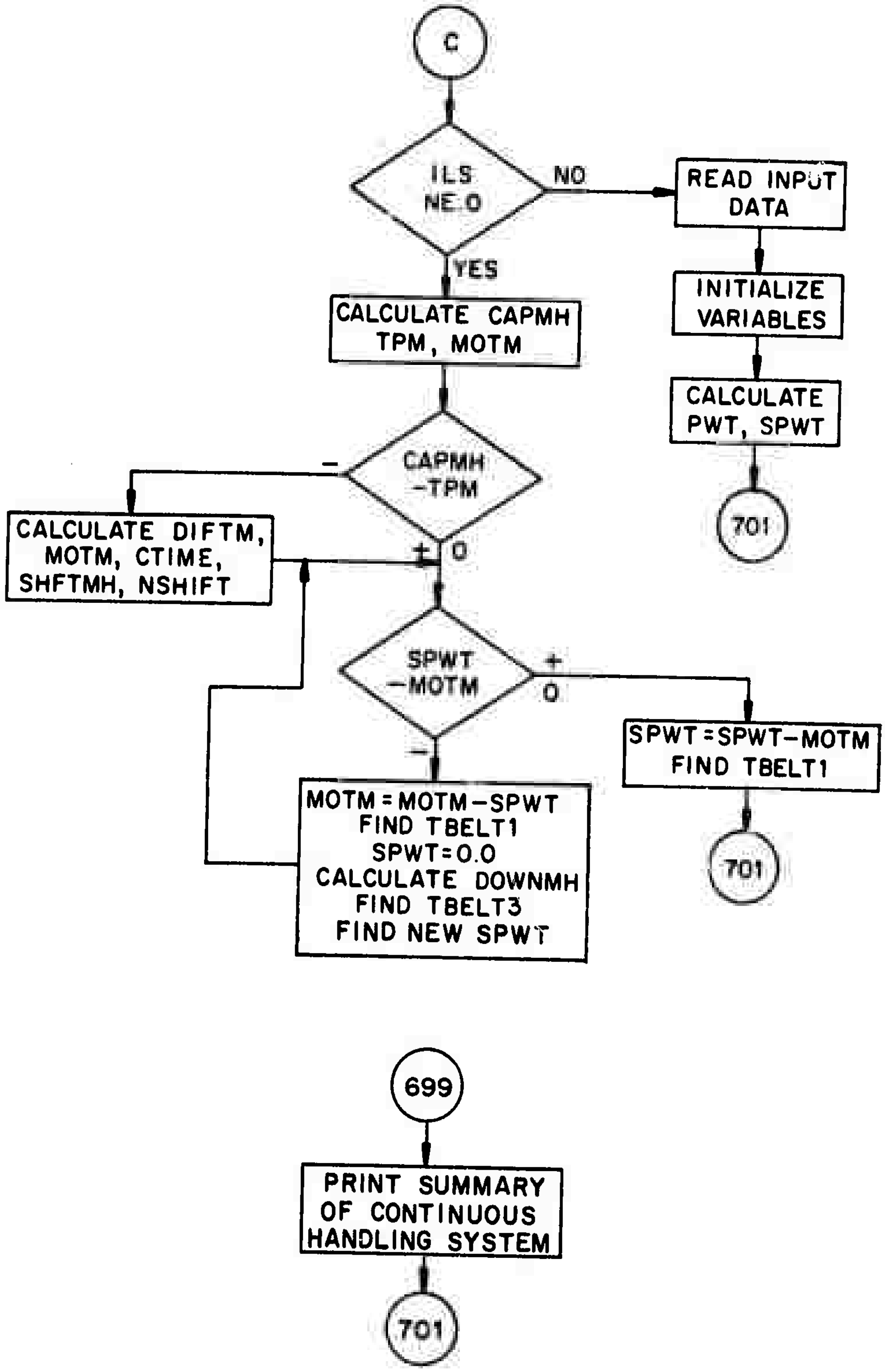
SUBROUTINE MOTION (CONT'D)



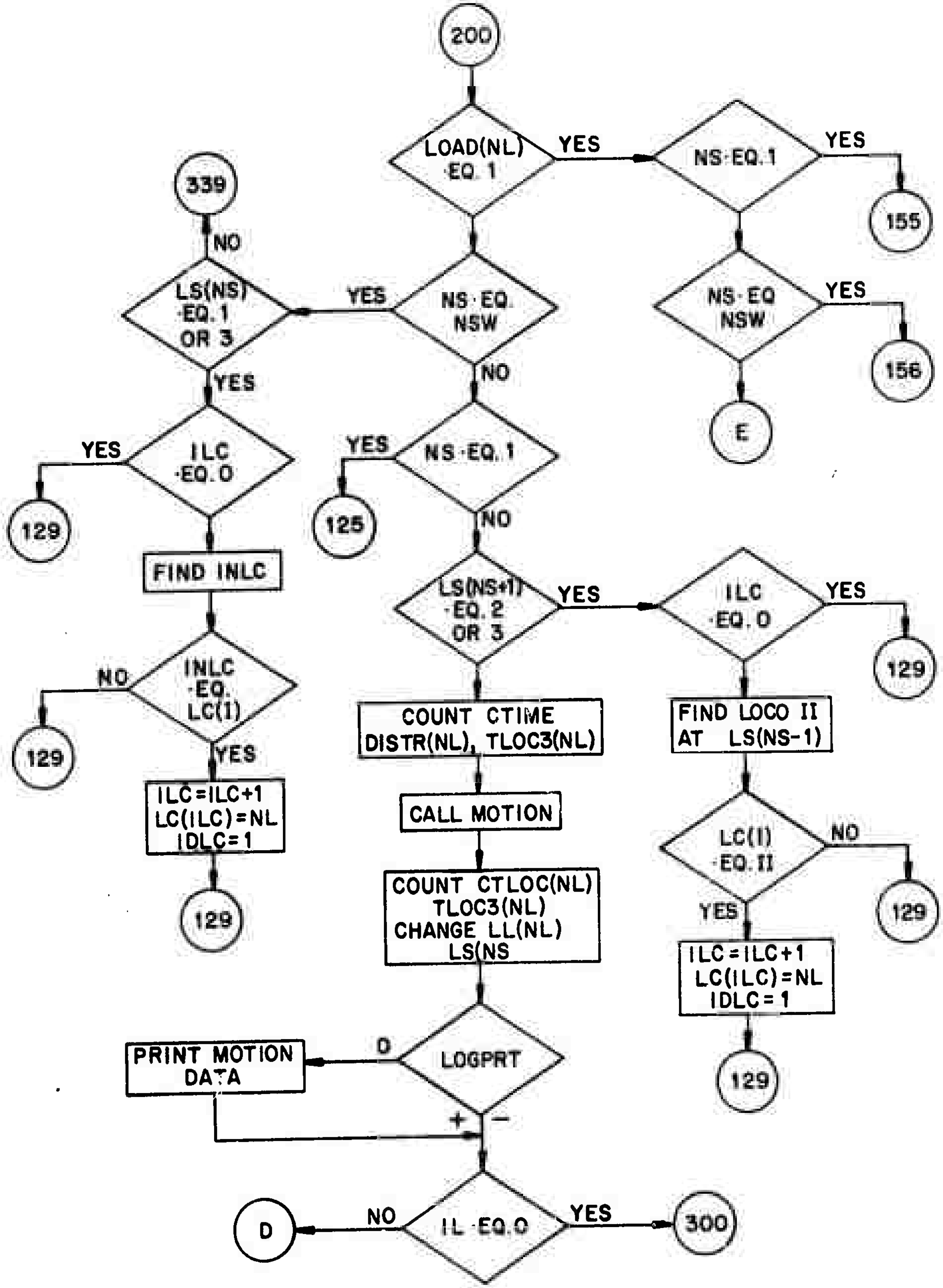
SUBROUTINE TRANS



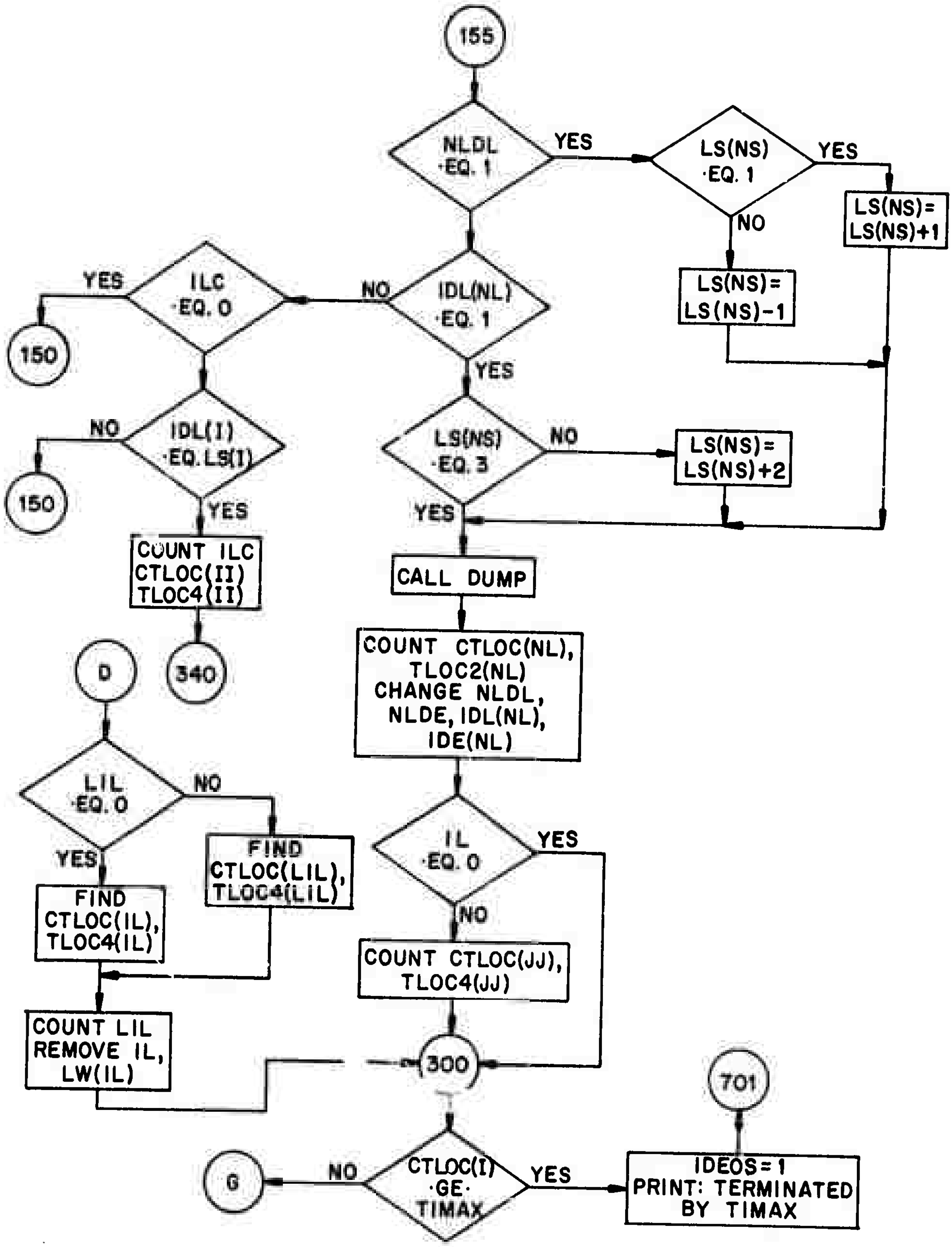
SUBROUTINE TRANS (CONT'D)



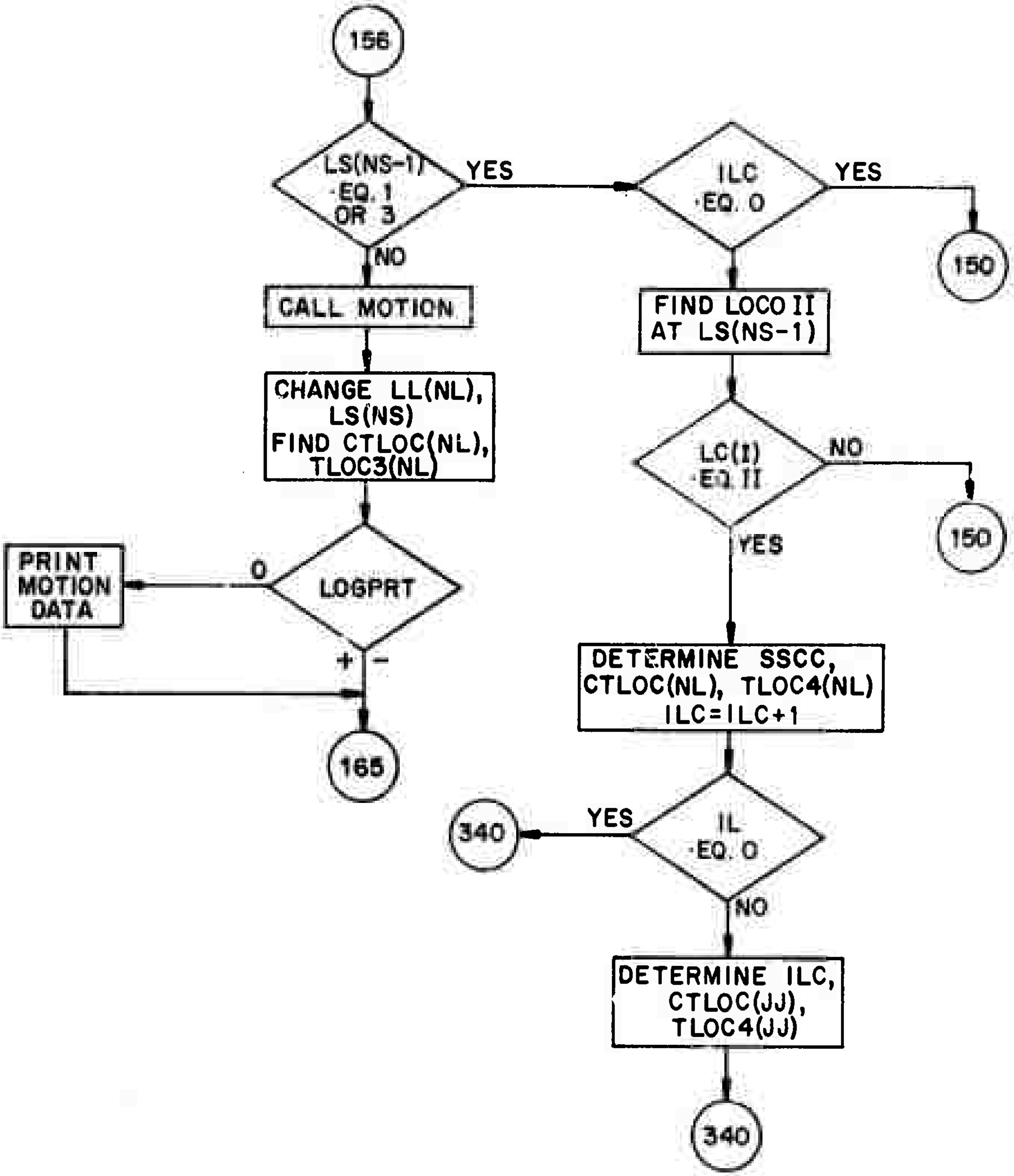
SUBROUTINE TRANS (CONT'D)



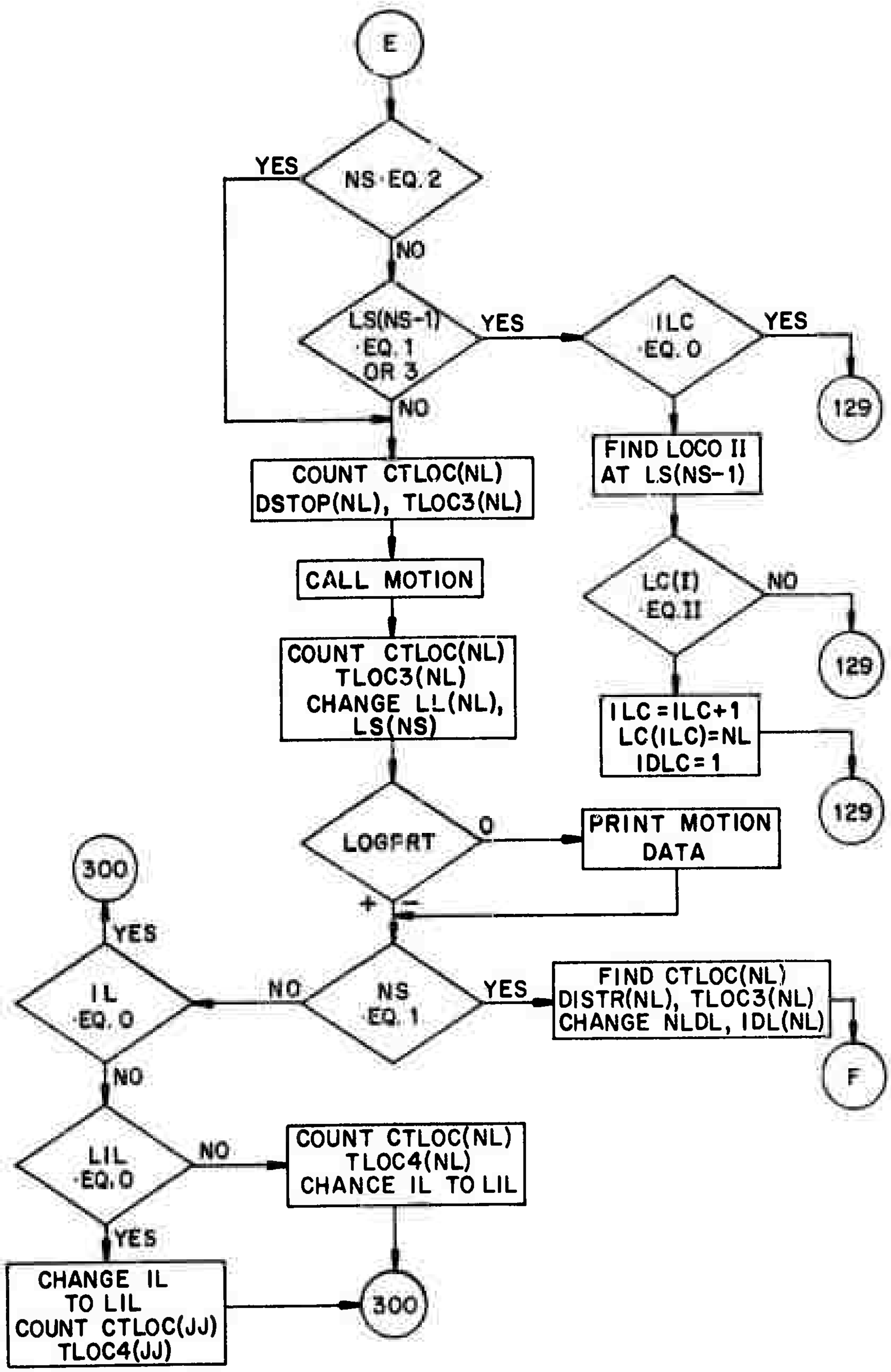
SUBROUTINE TRANS (CONT'D)



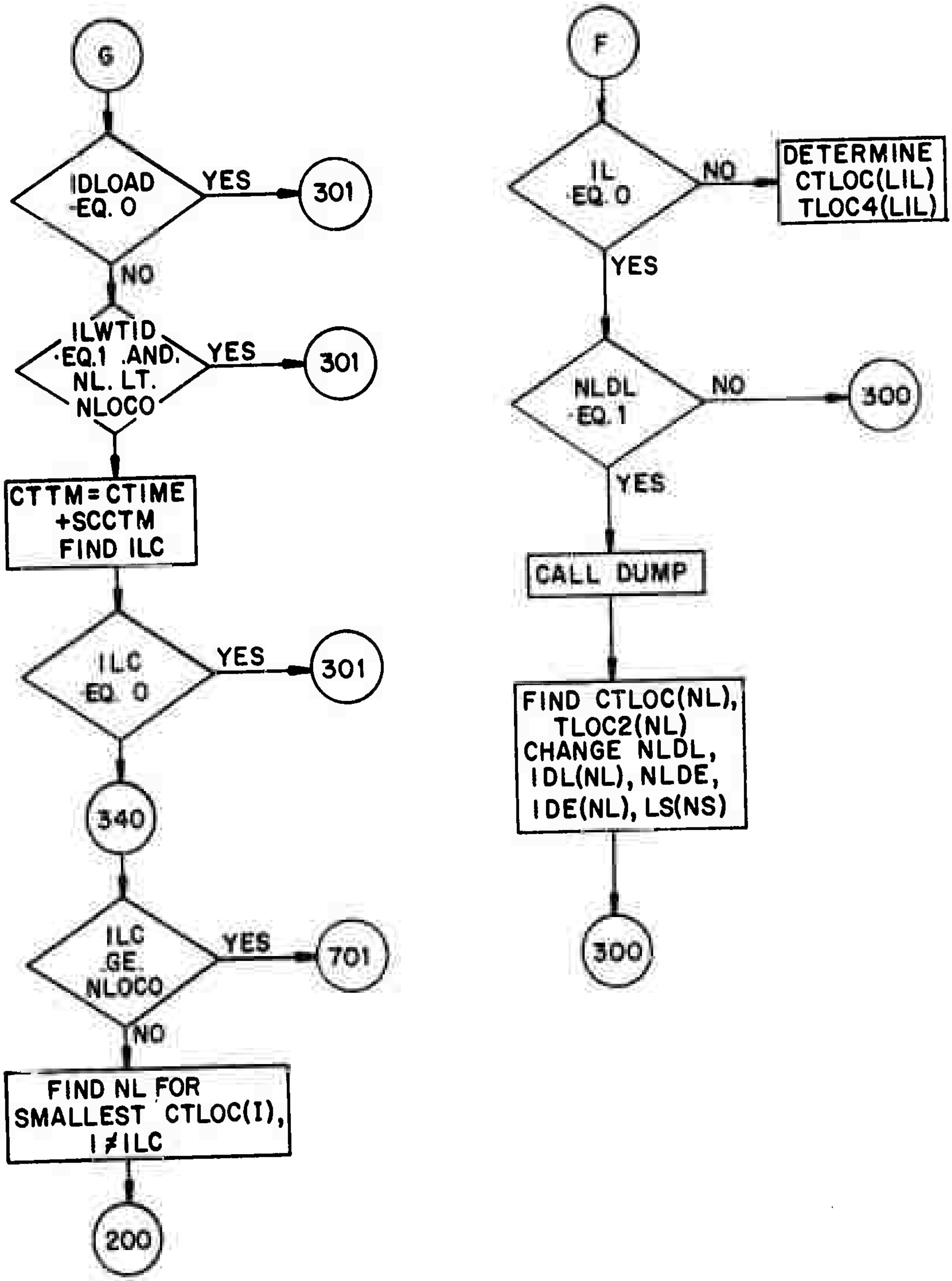
SUBROUTINE TRANS (CONT'D)



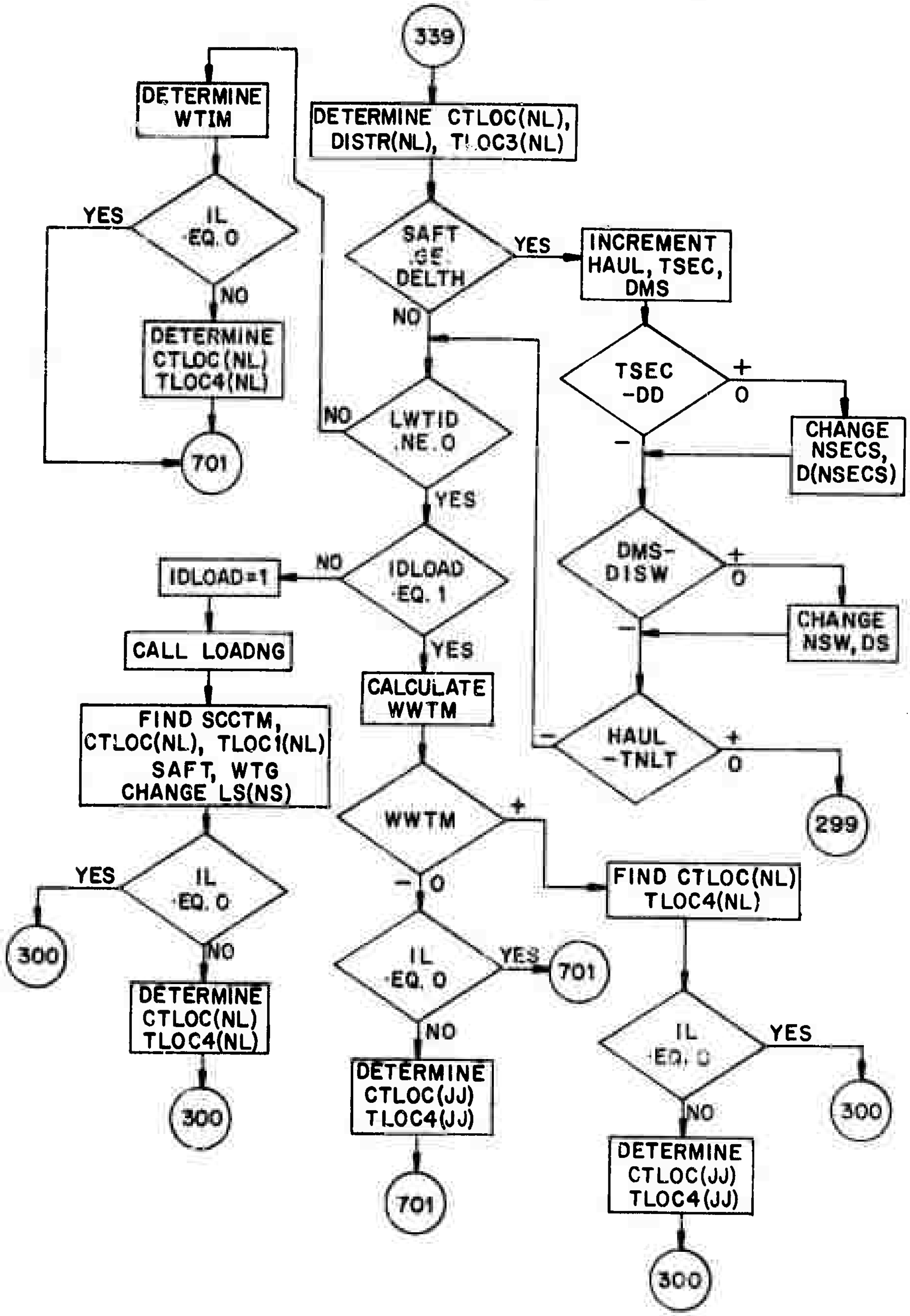
SUBROUTINE TRANS (CONT'D)



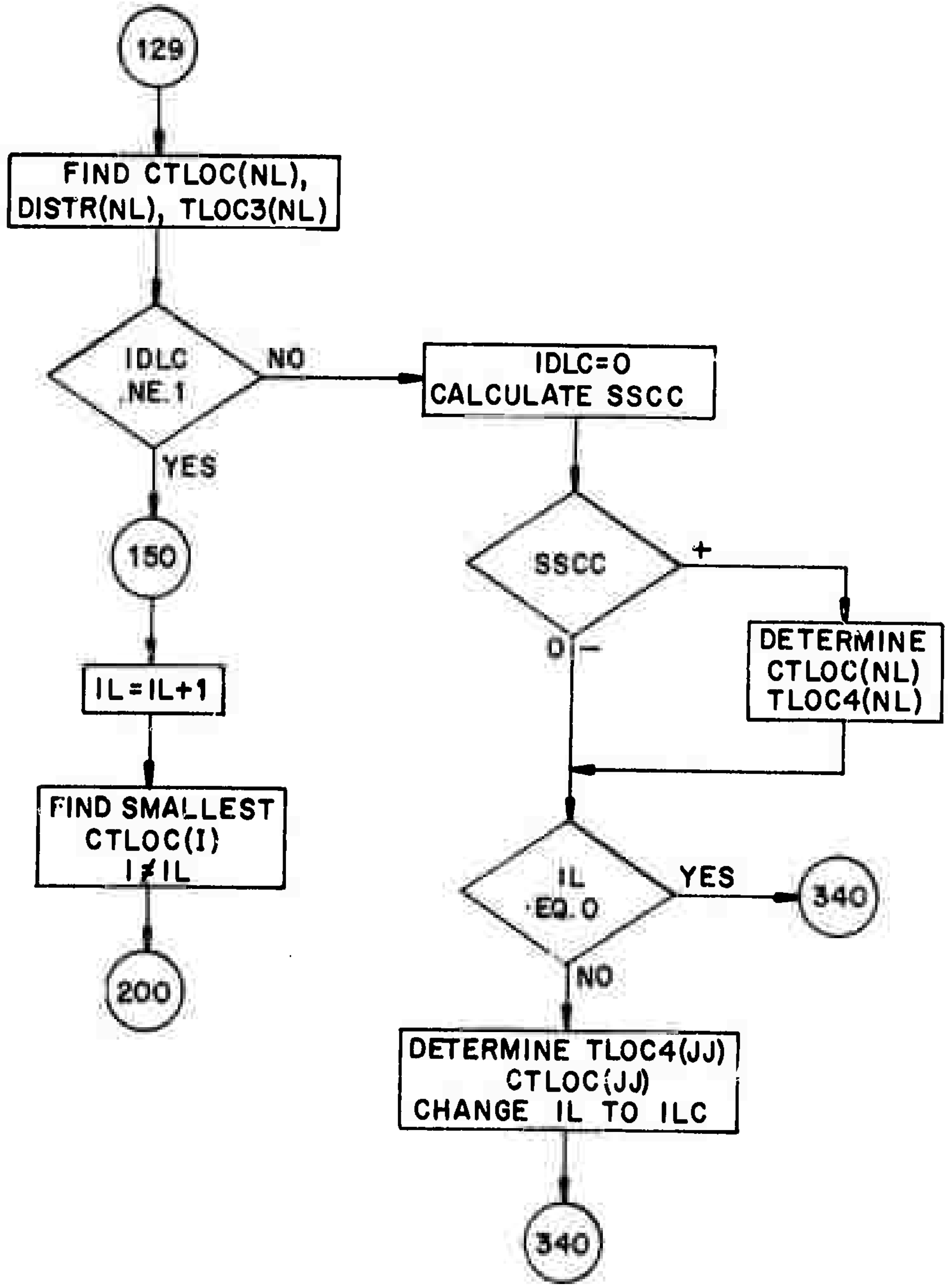
SUBROUTINE TRANS (CONT'D)



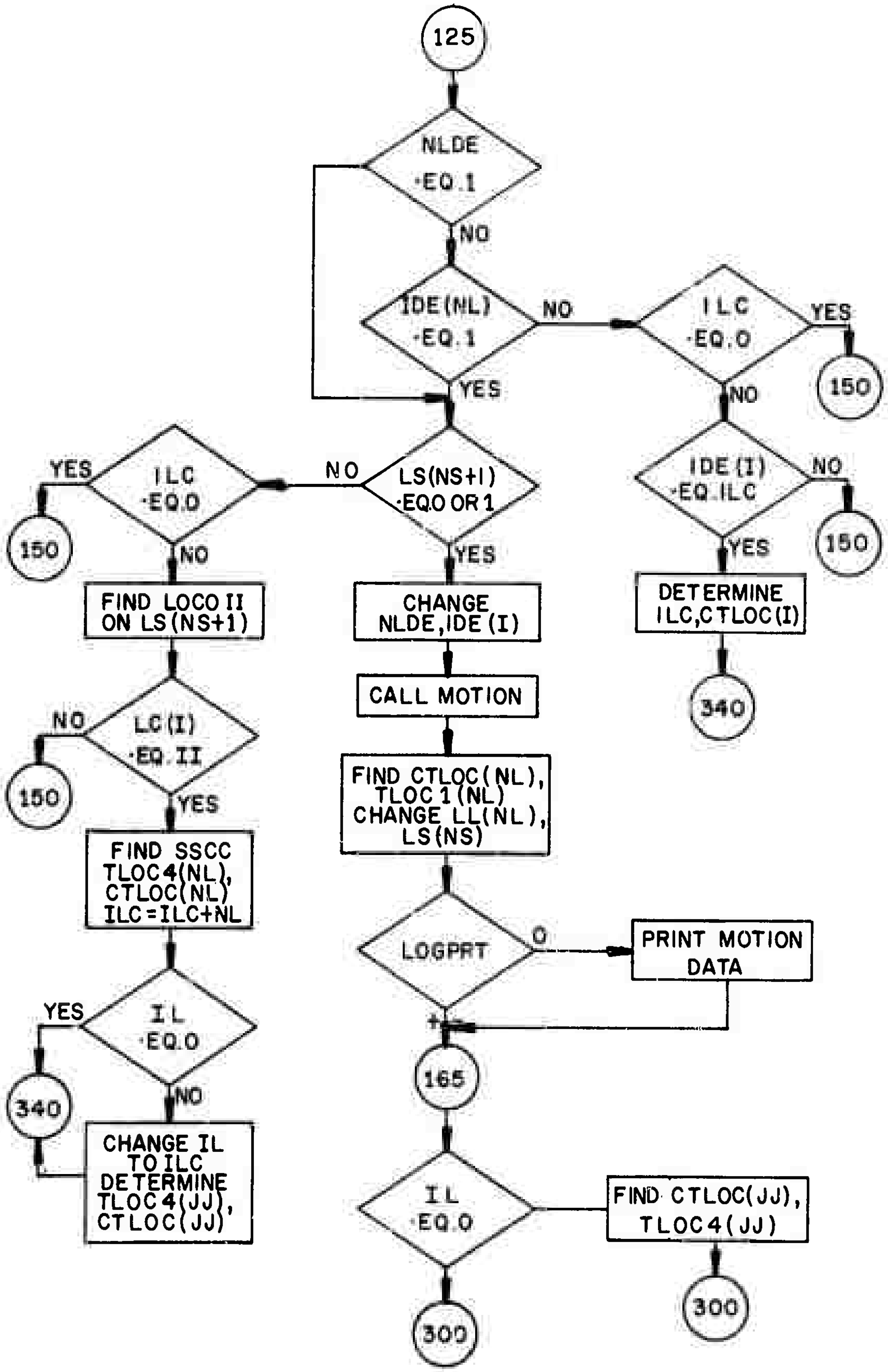
SUBROUTINE TRANS (CONT'D)



SUBROUTINE TRANS (CONT'D)



SUBROUTINE TRANS. (CONT'D)



The Computer Program

The computer model which is presented on the following pages consists of a main program and seven subroutines. The jobs performed by the individual subroutines are explained by the comment cards located at the beginning of each subroutine deck. The program was written for the Univac 1108 in standard FORTRAN IV and should be rather easy to transfer to other machines since few machine dependent statements were used. One aspect of the program which may need attention is the random number generator. The Univac 1108 used at the University of Utah uses the function RAND(N) to assign a random number uniformly distributed between zero and one to any variable. For example, the statement Y=RAND(N) will result in a random number between zero and one being assigned to the variable Y. Users wishing to use the program will have to check the random number function for their machines and, if necessary, replace all the statements calling random numbers with statements specific to their own machines.

```
      DIMENSION IXRR(20),IXX(20)
      DIMENSION MAN(120,2), XX(120), IX(120), IXR(120), XIXR(20),
     $MANAW(20), ACI(20), LOG(20), WORK(20), CTM(20), JON(20) ,
     $ IBIT(50), ACTIM(20)
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,L1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWIID,TTM,INL,TIMAX,NRBG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),IPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CT(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE
C
C     READ IN CONTROL CARDS
C
      READ 94, NRBG
   94 FORMAT ( I5)
      READ 93 ( CFR(I), FTA(I), I=1,NRBG )
   93 FORMAT ( 2F10.5)
      READ 95, RADIUS,GAMMA
   95 FORMAT ( 2F10.3)
      CROSEC=3.14159*RADIUS*RADIUS
      READ 96, NBITS, NACF, NCREW,ICYCLE
   96 FORMAT ( 4I10)
      READ 97, TIMAX, TNL, MAXSHT
   97 FORMAT ( 2F15.4, I10 )
      READ 98, LOGPRT, MH
   98 FORMAT ( 2I5 )
      READ 99, CTIME, TUNNEL, HRPSH, TOLIT
   99 FORMAT ( 4F10.3)
      READ 100, BINSMH,STROKE,INSPM
  100 FORMAT ( 2F10.3,I5)
      NSCF=NBITS*2 + NACF
      NCF=NBITS*2 + NACF*2-1
C
C     INITIALIZE THE VARIABLES
C
      DO 101 I=1,NCF
      DO 102 JJ=1,2
  102 MAN(I,JJ)=0
      DO 101 J=1,13
      CF(I,J)=0.0
  101 TV(I,J)=0.0
      MREST=0
      RESTMH=0.0
      WAITM=0.0
      NSHIFT=0
```

```
      TBIT1=0.0
      TBIT2=0.0
      TBIT3=0.0
      TBIT4=0.0
      TBIT5=0.0
      TMOLE1=0.0
      TMOLE2=0.0
      TMOLE3=0.0
      THIRD1=0.0
      THIRD2=0.0
      THIRD3=0.0
      ID=10
      ILS=0
      ILWTID=0
      IDEOS=0
      SWTTIM=0.0
      TSUPPT=0.0
C
C     READ IN CUMULATIVE PROBABILITY FUNCTIONS
C
      DO 103 I=1,NCF
      READ 104, NCLAS(I)
  104 FORMAT ( I10)
      NJ=NCLAS(I)
      DO 110 J=1,NJ
  110 READ 105, CF(I,J), TV(I,J)
  105 FORMAT ( 2F10.5)
  103 CONTINUE
C
C     READ IN THE UPPER AND LOWER LIMITS OF NUMBER OF MEN
C      REQUIRED FOR EACH ACTIVITY
C     MAN(I,1)=LOWER LIMIT
C     MAN(I,2)=UPPER LIMIT
C
      READ 106, MNBITL,MNBITU
      N1=NBITS
      DO 107 I=1,N1
      MAN(I,1)=MNBITL
  107 MAN(I,2)=MNBITU
  106 FORMAT ( 2I10 )
      N2=N1*2+1
      N3=NSCF-1
      READ 109 ((MAN(I,J), J=1,2), I=N2,N3)
  109 FORMAT ( 12I5)
C
C     CALL SUBROUTINE CALCUM TO OBTAIN ABSCISSA VALUES CORRESPONDING
C      TO CF(I) = RAND
```

```
C
      DO 150 I=1,NCF
      ICF=I
C
      CALL CALCUM(ICF,X)
C
  150 XX(I)=X
C
C     COMPUTE MANHOURS AND NUMBER OF MEN AVAILABLE FOR THE SHIFT
C
      NSHIFT=NSHIFT+1
      SHFTMH=HRPSH*NCREW
      IMAN=NCREW
C
C     IF WANTED, PRINT LOG OF OPERATIONS
C
      IF (LOGPRT) 995,160,995
  160 PRINT 161
  161 FORMAT ( 1H1,'*****LOG OF OPERATIONS*****' //)
  162 FORMAT ( 1H0,' CLOCK TIME',5X,'COMPLETED EVENT   ',3X,' MAN HOUR'
     $ 5X,'TUNNEL LENGTH' )
C
C     SEARCH FOR THE SHORTEST LIFE OF THE UNIT IN THE SYSTEM
C

  995 IF ( ILS .NE. 0 ) GO TO 89
C
      CALL TRANS
C
   89 CONTINUE
      ILS=ILS+1
      ADRT=XX(NSCF)
      XX(NSCF)=XX(NSCF)/60.0
      IF ( ICYCLE .EQ. 0) GO TO 829
C
      CALL MUCK
C
      TEMPWT=WTMUCK
  829 TEMSTR=STROKE
  999 IN=NSCF-1
      IL1=NBITS*2+2
      M=NBITS*2+1
      KK=M
      DO 170 I=IL1,IN
  170 IF ( XX(I) .LT. XX(M)) M=I
      ITEM=M
C
C     COUNT NUMBER OF EVENTS HAVING THE SAME LIFE
C
      ICOUNT=0
      LLL=ITEM-1
      MM=ITEM+1
      SX=XX(ITEM)
```

```
      IF ( ITEM .EQ. KK ) GO TO 314
      DO 311 I=KK,LLL
      XI=XX(I)
      DIF=ABS(SX-XI)
      IF ( DIF .GT. TOLIT ) GO TO 311
      ICOUNT=ICOUNT+1
      II=ICOUNT+1
      IX(II)=I
  311 CONTINUE
      IF ( ITEM .EQ. IN ) GO TO 315
  314 DO 312 J=MM,IN
      XI=XX(J)
      DIF=ABS(SX-XI)
      IF ( DIF .GT. TOLIT) GO TO 312
      ICOUNT=ICOUNT +1
      II=ICOUNT+1
      IX(II)=J
  312 CONTINUE
  315 CONTINUE
      NEVENT=ICOUNT+1
      IX(1)=ITEM
C
C     COMPUTE THE TIME FOR ADVANCING AND THE DISTANCE TO BE ADVANCED
C
      IF (MH) 355,356,355
  356 TTM=XX(ITEM)
      TFT=XX(NSCF)*XX(ITEM)
      GO TO 357
  355 TFT=XX(ITEM)
      TTM=XX(ITEM)/XX(NSCF)
  357 TMH=TTM*NCREW /60.0
C
C     COMPARE TFT WITH STROKE
C
  987 IF ( TFT-TEMSTR) 350,352,352
C
C     ADVANCE BY TEMSTR ( CASE OF TEMSTR .LT.TFT )
C
  352 TTM=TEMSTR/XX(NSCF)
      TMH=TTM*NCREW/60.0
      WTLDG=CROSEC*TEMSTR *GAMMA/2000.0
      TFTA=TEMSTR
C
      CALL SUPPRT(TFTA,REQMH)
C
      SCCTM=0.0
      IF (ICYCLE .NE. 0) GO TO 760
      FTAD=TEMSTR
C
      CALL TRANS
C
```

```
      GO TO 413
  760 IF ( LS(NSW) .EQ. 0  .OR. LS(NSW) .EQ.1) GO TO 751
      LWTID=1
      GO TO 752
  751 LWTID=0
C
      CALL TRANS
C
      CTIME=CTIME+WTIM
      TMOLE2=TMOLE2+WTIM
      TBIT2=TBIT2+WTIM
      THIRD2=THIRD2+WTIM
  752 IF ( WTLDG-TEMPWT) 753,754,755
  753 TEMPWT=TEMPWT-WTLDG
      DO 756 I=1,NLOCO
  756 IF ( LL(I) .EQ. NSW) GO TO 757
      PRINT 758
  758 FORMAT ( 1H0,'LOADING WAS ATTEMPTED WITHOUT EMPTY TRAIN AT LOADING
     $ POINT')
      STOP
  757 JJ=I
      CTLOC(JJ)=CTLOC(JJ)+TMUCK
      TLOC1(JJ)=TLOC1(JJ)+TMUCK
      GO TO 413
  754 TEMPWT=0.0
      ILWTID=ILWTID+1
      IDLOAD=0
C
      CALL TRANS
C
      IF ( IDEOS .EQ. 1) GO TO 520
C
      CALL MUCK
C
      TEMPWT=WTMUCK
      GO TO 413
  755 WTLDG=WTLDG-TEMPWT
      TEMPWT=0.0
      ILWTID=ILWTID+1
      IDLOAD=0
C
      CALL TRANS
C
      IF ( IDEOS .EQ. 1) GO TO 520
C
      CALL MUCK
C
      TEMPWT=WTMUCK
      GO TO 760
C
```

```
C     CHECK TO SEE IF THE ADVANCE CAN BE COMPLETED IN THE SHIFT
C
  413 IF ( SHFTMH-TMH) 411,412,412
  411 SHFTMH=SHFTMH+NCREW*HRPSH
      NSHIFT=NSHIFT+1
      GO TO 413
  412 SHFTMH=SHFTMH-TMH
      TUNNEL=TUNNEL +TEMSTR
      TBIT1=TBIT1+TTM
      TMOLE1=TMOLE1+TTM
      THIRD1=THIRD1+TTM
      CTIME=CTIME+TTM
      AVAMH=TTM*2.0/60.0
      IF ( REQMH-AVAMH) 835,835,836
  836 WTTIM=((REQMH-AVAMH)/2.0)*60.0
      SWTTIM=SWTTIM+WTTIM
      CTIME=CTIME+WTTIM
      TBIT2=TBIT2+WTTIM
      TMOLE2=TMOLE2+WTTIM
      THIRD2=THIRD2+WTTIM
      MREST=MREST + (NCREW-2)
      RESTMH=RESTMH+WTTIM*(NCREW-2)/60.0
      WAITM=WAITM+WTTIM
      WTTMH=WTTIM*NCREW/60.0
  890 IF ( SHFTMH-WTTMH) 830,832,832
  830 SHFTMH=SHFTMH+NCREW*HRPSH
      NSHIFT=NSHIFT+1
      GO TO 890
  832 SHFTMH=SHFTMH-WTTMH
      TSUPPT=TSUPPT+TTM+WTTIM
      GO TO 891
  835 TSUPPT=TSUPPT+TTM
  891 CONTINUE
      TFT=TFT-TEMSTR
      TEMSTR=STROKE
      IF (LOGPRT) 481,480,481
  480 PRINT 162
      PRINT 362, CTIME, TMH, TUNNEL
C
C     INSPECTION
C
  481 IF (IMAN-INSPM)450,451,451
  450 MREST=IMAN+MREST
      RESTMH=SHFTMH+RESTMH
      IF ( IMAN .EQ. 0) GO TO 892
      WAITM=WAITM+(SHFTMH/IMAN)*60.0
      CTIME=CTIME+(SHFTMH/IMAN)*60.0
  892 NSHIFT=NSHIFT+1
      SHFTMH=HRPSH*NCREW
      IMAN=NCREW
  451 IF (SHFTMH-BINSMH) 452,453,453
  452 SHFTMH=SHFTMH+NCREW*HRPSH
```

```
      NSHIFT=NSHIFT+1
  453 SHFTMH=SHFTMH-BINSMH
      TBINSP=(BINSMH/INSPM )*60.0
      TBIT5=TBIT5+TBINSP
      CTIME=CTIME+TBINSP
      TMOLE2=TMOLE2+TBINSP
      THIRD2=THIRD2+TBINSP
      MREST=(NCREW-INSPM) +MREST
      RESTMH=RESTMH+(NCREW-INSPM)*TBINSP/60.0
      IF (LOGPRT) 483,482,483
  482 PRINT 162
      PRINT 484,CTIME, BINSMH, TUNNEL
  484 FORMAT (1H , F10.3, 5X,'  BIT INSPECTION ', 3X,F10.3,3X, F10.3)
C
C     COUNT NUMBER OF BITS TO BE REPLACED, IF ANY
C
  483 KOUNT=0
      IF ( ID .EQ. 1) GO TO 668
      TOLSTR=STROKE+TOLIT
      GO TO 669
  668 TOLSTR=STROKE-TEMSTR+IFT+TOLIT
  669 DO 415 I=1,NBITS
      IF (MH) 416,417,416
  417 XX(I)=XX(I)*XX(NSCF)
  416 IF ( XX(I) .GT. TOLSTR ) GO TO 415
      KOUNT=KOUNT+1
      K=KOUNT
      IBIT(K)=I
  415 CONTINUE
C
C     REPLACE BITS, IF ANY
C
      IF ( KOUNT .EQ. 0 ) GO TO 430
      DO 420 I=1,KOUNT
      ITEM=IBIT(I)
      IF ( IMAN-MAN(ITEM,1)) 421,422,423
  423 IF ( IMAN-MAN(ITEM,2)) 422,422,424
  428 IMAN=IMAN+MANWK
  421 MREST=IMAN+MREST
      RESTMH=RESTMH+SHFTMH
      IF ( IMAN .EQ. 0) GO TO 893
      WAITM=WAITM+(SHFTMH/IMAN)*60.0
      CTIME=CTIME+(SHFTMH/IMAN)*60.0
  893 NSHIFT=NSHIFT+1
      SHFTMH=HRPSH*NCREW
      IMAN=NCREW
  424 MANWK=MAN(ITEM,2)
```

```
      IMAN=IMAN-MANWK
      GO TO 425
  422 MANWK=IMAN
      IMAN=0
  425 ITEMH=ITEM+NBITS
      BMH=XX(ITEMH)
  429 IF (SHFTMH .LT. BMH) GO TO 428
      ACTM=(BMH/MANWK)*60.0
      TBIT4=TBIT4+ACTM
      CTIME=CTIME+ACTM
      TMOLE2=TMOLE2+ACTM
      THIRD2=THIRD2+ACTM
      SHFTMH=SHFTMH-BMH
      IF ( LOGPRT) 420,485,420
  485 PRINT 162
      PRINT 486, CTIME, BMH, TUNNEL,ITEM
  486 FORMAT (1H , F10.3,5X,'  BIT REPLACING  ', 3X, F10.3, 3X, F10.3,
     $ 3X,'BIT NO.', I3, 2X,'REPLACED')
  420 CONTINUE
C
C     SUBTRACT STROKE FROM BIT LIFE
C
  430 CONTINUE
      IF ( ID .NE. 1 ) GO TO 670
      AA=(STROKE-TEMSTR)+TFT
      GO TO 671
  670 AA=STROKE
  671 DO 431 I=1,NBITS
      IF (MH .NE. 0) GO TO 432
      AA=AA/XX(NSCF)
      GO TO 431
  432 AA=AA
  431 XX(I)=XX(I)-AA
C
C     REPLACE BIT LIFE OF BIT REMOVED WITH A NEW LIFE
C
      IF (KOUNT .EQ. 0) GO TO 438
      DO 435 I=1,KOUNT
      ITEM=IBIT(I)
      ITEMH=ITEM+NBITS
C
      CALL CALCUM(ITEMH,X)
C
      XX(ITEMH)=X
C
      CALL CALCUM(ITEM,X)
C
  435 XX(ITEM)=X
  438 IF ( ID .NE. 1) GO TO 577
      ID=ID+1
      TEMSTR=STROKE
      GO TO 998
  577 ICF=NSCF
```

```
C
      CALL CALCUM ( ICF,X)
C
      XX(NSCF)=X
      AURT=XX(NSCF)
      XX(NSCF)=XX(NSCF)/60.0
      IF ( ICYCLE .EQ. 0) GO TO 838
C
      CALL MUCK
C
  838 TTM=TFT/XX(NSCF)
      TMH=TTM*NCREW/60.0
      IF ( TNL-TUNNEL) 950,950,951
  951 IF ( MAXSHT-NSHIFT) 952,952,953
  953 IF ( TIMAX-CTIME) 954,954,987
  950 PRINT 507
      GO TO 520
  952 PRINT 512
      GO TO 520
  954 PRINT 513
      GO TO 520
C
C     COMPLETED INSPECTION AND REPLACING OF BITS
C     ADVANCE BY TFT (CASE OF TEMSTR .GE. TFT)
C
  350 CONTINUE
      TFTA=TFT
C
      IF ( TFT ) 771,361,771
  771 WTLDG=CROSEC*TFT*GAMMA/2000.0
      SCCTM=0.0
      IF ( ICYCLE .NE. 0) GO TO 710
      FTAD=TFT
C
      CALL TRANS
C
      GO TO 369
  710 IF ( LS(NSW) .EQ. 0  .OR. LS(NSW) .EQ.1) GO TO 701
      LWTID=1
      GO TO 702
  701 LWTID=0
C
      CALL TRANS
C
      CTIME=CTIME+WTIM
      TMOLE2=TMOLE2+WTIM
      TBIT2=TBIT2+WTIM
      THIRD2=THIRD2+WTIM
  702 IF ( WTLDG-TEMPWT) 703,704,705
  703 TEMPWT=TEMPWT-WTLDG
      DO 706 I=1,NLOCO
  706 IF ( LL(I) .EQ. NSW) GO TO 707
```

```
      PRINT 708
  708 FORMAT ( 1H0,'LOADING WAS ATTEMPTED WITHOUT EMPTY TRAIN AT LOADING
     $ POINT')
      STOP
  707 JJ=I
      CTLOC(JJ)=CTLOC(JJ)+TMUCK
      TLOC1(JJ)=TLOC1(JJ)+TMUCK
      GO TO 369
  704 TEMPWT=0.0
      ILWTID=ILWTID+1
      IDLOAD=0
C
      CALL TRANS
C
      IF ( IDEOS .EQ. 1) GO TO 520
C
      CALL MUCK
C
      TEMPWT=WTMUCK
      GO TO 369
  705 WTLDG=WTLDG-TEMPWT
      TEMPWT=0.0
      ILWTID=ILWTID+1
      IDLOAD=0
C
      CALL TRANS
C
      IF ( IDEOS .EQ. 1) GO TO 520
C
      CALL MUCK
C
      TEMPWT=WTMUCK
      GO TO 710
C
C     CHECK WHETHER THE PROJECTED BORING CAN BE DONE IN THE SHIFT
C
  369 IF (SHFTMH-TMH) 358,359,359
  358 SHFTMH=SHFTMH+NCREW*HRPSH
      NSHIFT=NSHIFT+1
      GO TO 369
  359 SHFTMH=SHFTMH-TMH
      TUNNEL=TUNNEL +TFT
      TBIT1=TBIT1+TTM
      TMOLE1=TMOLE1+TTM
      THIRD1=THIRD1+TTM
      CTIME=CTIME+TTM
C
      CALL SUPPRT(TFTA,REQMH)
C
      AVAMH=TTM*2.0 /60.0
      IF ( REQMH-AVAMH) 865,865,866
  866 WTTIM=((REQMH-AVAMH)/2.0)*60.0
```

```
      CTIME=CTIME+WTTIM
      SWTTIM=SWTTIM+WTTIM
      TBIT2=TBIT2+WTTIM
      TMOLE2=TMOLE2+WTTIM
      THIRD2=THIRD2+WTTIM
      MREST=MREST + (NCREW-2)
      RESTMH=RESTMH+WTTIM*(NCREW-2)/60.0
      WTTMH=WTTIM*NCREW/60.0
  894 IF ( SHFTMH-WTTMH) 860,862,862
  860 SHFTMH=SHFTMH+NCREW*HRPSH
      NSHIFT=NSHIFT+1
      GO TO 894
  862 SHFTMH=SHFTMH-WTTMH
      TSUPPT=TSUPPT+TTM+WTTIM
      GO TO 895
  865 TSUPPT=TSUPPT+TTM
  895 CONTINUE
C
      CALL CALCUM(NSCF,X)
C
      XX(NSCF)=X
      ADRT=XX(NSCF)
      XX(NSCF)=XX(NSCF)/60.0
      IF ( ICYCLE .EQ. 0) GO TO 837
C
      CALL MUCK
C
  837 IF (LOGPRT) 361,360,361
  360 PRINT 162
      PRINT 362, CTIME, TMH, TUNNEL
  362 FORMAT (1H ,F10.3, 5X, '  TUNNEL BORING  ',3X, F10.3,3X,F10.3)
C
C     DETERMINE REPAIR TIME
C
  361 DO 370 K=1,NEVENT
      M=NBITS*2+1
      N=NSCF-1
      JCOUNT=0
      ITEM=IX(K)
      DO 365 J=M,N
      JCOUNT=JCOUNT+1
  365 IF(ITEM .EQ. J) GO TO 366
      PRINT 367, ITEM
  367 FORMAT (' EVENT NUMBER = ', I3, 'COULD NOT BE FOUND IN CF(I,J) ARR
     $AY, SO RUN STOPPED')
      STOP
  366 IR=NSCF+JCOUNT
  370 IXR(K)=IR
C
C     START REPAIRS
C     MAKE AN ARRAY OF IXR(I) IN DECENDING ORDER
C
```

```
      IF ( NEVENT .EQ. 1) GO TO 371
      DO 372 I=1,NEVENT
      IR=IXR(I)
  372 XIXR(I)=XX(IR)
      NA=NEVENT-1
      DO 373 J=1,NA
      M=J
      MA=J+1
      DO 374 K=MA,NEVENT
  374 IF (XIXR(K) .GT. XIXR(M)) M=K
      TEMP=XIXR(J)
      XIXR(J)=XIXR(M)
  373 XIXR(M)=TEMP
      MKL=IXR(1)
      DO 840 KL=2,NEVENT
      IR=IXR(KL)
      IF ( XX(MKL)-XX(IR)) 840,371,840
  840 CONTINUE
      DO 375 I=1,NEVENT
      IR=IXR(I)
      DO 376 J=1,NEVENT
      IF (XIXR(J)-XX(IR)) 376,377,376
  376 CONTINUE
  377 IXRR(J)=IR
  375 IXX(J)=IR-(NSCF-NBITS*2)
      DO 645 I=1,NEVENT
      IX(I)=IXX(I)
  645 IXR(I)=IXRR(I)
C
  371 ISUM1=0
      ISUM2=0
C
C     TO DISTRIBUTE MEN TO CREWS, THE BIGGER JOBS ARE ASSIGNED
C      MANPOWER FIRST
C
      DO 380 I=1,NEVENT
      ITEM=IX(I)
      ISUM1=ISUM1+MAN(ITEM,1)
  380 ISUM2=ISUM2+MAN(ITEM,2)
      DO 500 KK=1,NEVENT
      IR=IXR(KK)
      ITEM=IX(KK)
      I=KK
      IF (IMAN-ISUM1) 381,382,383
  383 IF ( IMAN-ISUM2) 381,384,384
  382 MANAW(I)=MAN(ITEM,1)
      GO TO 395
  384 MANAW(I)=MAN(ITEM,2)
      GO TO 395
  381 IF (IMAN-MAN(ITEM,1)) 390,391,392
  392 IF (IMAN-MAN(ITEM,2)) 391,391,393
  390 MREST=MREST+IMAN
```

```
      RESTMH=RESTMH+SHFTMH
      IF ( IMAN .EQ. 0) GO TO 846
      WAITM=WAITM+(SHFTMH/IMAN)*60.0
      CTIME=CTIME+(SHFTMH/IMAN)*60.0
  846 NSHIFT=NSHIFT+1
      SHFTMH=NCREW*HRPSH
      IMAN=NCREW
  393 MANAW(I)=MAN(ITEM,2)
      GO TO 395
  391 MANAW(I)=IMAN
      GO TO 395
  395 IMAN=IMAN-MANAW(I)
C
C     IF A JOB CANNOT BE HANDLED IN SHIFT, IT IS EXTENDED INTO
C      THE NEXT SHIFT
C
      IF (SHFTMH .GE. XX(IR)) GO TO 396
  397 SHFTMH=SHFTMH+NCREW*HRPSH
      NSHIFT=NSHIFT+1
      IMAN=NCREW-MANAW(I)
      IF (SHFTMH .LT. XX(IR)) GO TO 397
  396 SHFTMH=SHFTMH-XX(IR)
      WORK(I)=XX(IR)
  500 ACTIM(I)=(WORK(I)/MANAW(I))*60.0
C
C     ARRANGE ACTIM(I) IN ASCENDING ORDER
C
      IF (NEVENT .EQ. 1) GO TO 550
      DO 557 I=1,NEVENT
  557 ACT(I)=ACTIM(I)
      NA=NEVENT-1
      DO 551 J=1,NA
      M=J
      MA=J+1
      DO 552 I=MA,NEVENT
  552 IF (ACT(I) .LT. ACT(M)) M=I
      TEMP=ACT(J)
      ACT(J)=ACT(M)
  551 ACT(M)=TEMP
      DO 558 K=1,NEVENT
      DO 559 I=1,NEVENT
      IF (ACTIM(I)-ACT(K)) 559,558,559
  559 CONTINUE
  558 LOG(K)=I
      GO TO 553
  550 ACT(1)=ACTIM(1)
      LOG(1)=1
  553 IF ( NEVENT .EQ. 1) GO TO 630
C
C     REDUCE THE VALUES OF ACTIM(I) BY REDISTRIBUTING THE MANPOWER
C      AFTER ACTIM(1) IS ACHEIVED
C
```

```
      J=1
      DO 600 L=NEVENT,2,-1
      I=L
  620 M=LOG(I)
      IR=IXR(M)
      ITEM=IR-(NSCF-NBITS*2)
      IF (MAN(ITEM,2) .EQ. MANAW(M)) GO TO 471
      MAD=MAN(ITEM,2)-MANAW(M)
  610 IF (MAD-MANAW(J)) 601,602,602
  602 MTB=MANAW(J)
      IF ( J .NE. 1) GO TO 603
      DN=WORK(M)-ACT(J)*MANAW(M)/60.0
      DD=MANAW(M)+MTB
      GO TO 604
  603 DN=DN-(ACT(J)-ACT(J-1))*DD/60.0
      DD=DD+MTB
  604 ACT(I)=ACT(J)+(DN/DD)*60.0
      J=J+1
      IF (I-J) 605,606,607
  605 PRINT 608
  608 FORMAT (1X,'RUN STOPPED BY AN ERROR, SEE STATEMENT 605 IN MAIN')
      STOP
  607 MAD=MAD-MTB
      IF ( I .NE. NEVENT) GO TO 609
      IF ( ACT(I)-ACT(I-1)) 600,610,610
  609 IL=I+1
      DO 611 K=IL,NEVENT
  611 IF ( ACT(K) .GT. ACT(1)) GO TO 612
      IF ( ACT(I)-ACT(I-1)) 600,610,610
  612 I=K
      GO TO 620
  606 IF (ACT(I)-ACT(I-1)) 613,471,471
  613 PRINT 614
  614 FORMAT (1X,'RUN STOPPED BY AN ERROR, SEE STATEMENT 606 IN MAIN')
      STOP
C
C     THE CASE OF MAD .GE. MANAW(J) IS COMPLETED
C      THE CASE OF MAD .LT. MANAW(J) IS BEGUN
C
  601 MTB=MAD
      MANAW(J)=MANAW(J)-MTB
      IF (J .NE. 1) GO TO 621
      DN=WORK(M)-ACT(J)*MANAW(M)/60.0
      DD=MANAW(M)+MTB
      GO TO 622
  621 DN=DN-(ACT(J)-ACT(J-1))*DD/60.0
      DD=DD+MTB
  622 ACT(I)=ACT(J)+(DN/DD)*60.0
      IF ( I .NE. NEVENT) GO TO 623
      IF ( ACT(I)-ACT(I-1)) 600,471,471
  623 IL=I+1
      DO 624 K=IL,NEVENT
  624 IF ( ACT(K) .GT. ACT(1)) GO TO 625
```

```
      IF ( I-(J+1)) 626,627,628
  626 PRINT 629
  629 FORMAT (1X,'RUN STOPPED BY AN ERROR, SEE STATEMENT 626 IN MAIN'I
      STOP
  627 GO TO 471
  628 IF ( ACT(I)-ACT(I-1)) 600,471,471
  625 I=K
      GO TO 620
  600 CONTINUE
C
C     COMPLETE THE REDUCTION OF THE ACTIM(I) VALUES
C     REARRANGE ACT(I) IN ASCENDING ORDER
C
  471 CONTINUE
      DO 631 L=1,NEVENT
  631 JON(L)=0
      IM=1
      DO 632 K=1,NEVENT
      DO 633 IK=1,NEVENT
      MM=JON(IK)
  633 IF (IM .EQ. MM) IM=IM+1
      M=IM
      DO 634 I=1,NEVENT
      DO 635 N=1,NEVENT
      JJ=JON(N)
  635 IF ( JJ .EQ. I) GO TO 634
      IF (ACT(I)-ACT(M)) 636,634,634
  636 M=I
  634 CONTINUE
      CTM(K)=ACT(M)
      JON(K)=M
  632 CONTINUE
      GO TO 472
  630 CTM(1)=ACT(1)
      JON(1)=LOG(1)
  472 IF ( LOGPRT) 473,470,473
  470 PRINT 162
  473 DO 455 K=1,NEVENT
      IK=JON(K)
      M=LOG(IK)
      IR=IXR(M)
      J=IR-NSCF
      TCT=CTIME+CTM(K)
      RJOB=WORK(M)
      GO TO (456,457,858),J
  456 TBIT3=TBIT3+CTM(K)
      IF ( LOGPRT) 455,275,455
  275 PRINT 459, TCT, RJOB, TUNNEL
  459 FORMAT (1H , F10.3, 5X,'    BIT REPAIR    ',3X, F10.3,3X,F10.3)
      GO TO 455
  457 TMOLE3=TMOLE3+CTM(K)
```

```
      IF ( LOGPRT) 455,276,455
  276 PRINT 460, TCT, RJOB, TUNNEL
  460 FORMAT (1H , F10.3,5X,'   MOLE REPAIR    ',3X,F10.3,3X,F10.3)
      GO TO 455
  858 THIRD3=THIRD3+CTM(K)
      IF ( LOGPRT) 455,277,455
  277 PRINT 461, TCT, RJOB, TUNNEL
  461 FORMAT (1H ,F10.3,5X,'   THIRD REPAIR  ',3X,F10.3,3X,F10.3)
  455 CONTINUE
C
C     DETERMINE CLOCK TIME AND WAITING TIME
C
      CTIME=CTIME+CTM(NEVENT)
      IF (NEVENT .EQ. 1) GO TO 404
      NA=NEVENT-1
      BIG=CTM(NEVENT)
      DO 400 I=1,NA
      WTM=BIG-CTM(I)
      IK=JON(I)
      M=LOG(IK)
      MREST=MREST+MANAW(M)
      RESTMH=RESTMH+(WTM*MANAW(M))/60.0
      IR=IXR(M)
      J=IR-NSCF
      GO TO (401,402,403), J
  401 TMOLE2=TMOLE2+WTM
      THIRD2=THIRD2+WTM
      GO TO 400
  402 TBIT2=TBIT2+WTM
      THIRD2=THIRD2+WTM
      GO TO 400
  403 TBIT2=TBIT2+WTM
      TMOLE2=TMOLE2+WTM
  400 CONTINUE
      GO TO 405
  404 MREST=MREST+(NCREW-MANAW(1))
      RESTMH=RESTMH+((NCREW-MANAW(1))*CTM(1))/60.0
      IR=IXR(1)
      J=IR-NSCF
      GO TO (406,407,408),J
  406 TMOLE2=TMOLE2+CTM(1)
      THIRD2=THIRD2+CTM(1)
      GO TO 405
  407 TBIT2=TBIT2+CTM(1)
      THIRD2=THIRD2+CTM(1)
      GO TO 405
  408 TBIT2=TBIT2+CTM(1)
      TMOLE2=TMOLE2+CTM(1)
C
C     SUBTRACT XX(ITEM) FROM XX(I)
C     END OF REPAIRS
C
```

```
  405 ITEM=IX(1)
      M=NBITS*2+1
      N=NSCF-1
      DO 490 I=M,N
  490 XX(I)=XX(I)-XX(ITEM)
C
C     REPLACE XX(ITEM) WITH NEW XX(ITEM)
C
      DO 495 J=1,NEVENT
      ITEM=IX(J)
C
      CALL CALCUM(ITEM,X)
C
      XX(ITEM)=X
      IR=IXR(J)
C
      CALL CALCUM(IR,X)
C
  495 XX(IR)=X
C
C     PERFORM A BIT INSPECTION IF THE MOLE IS DOWN FOR OTHER REPAIRS
C
      DO 555 I=1,NEVENT
      IR=IXR(I)
      IDR=IR-NSCF
  555 IF ( IDR .EQ. 2) GO TO 666
      GO TO 667
  666 ID=1
      IF ( ID .EQ. 1) GO TO 481
  667 TEMSTR=TEMSTR-TFT
  998 CONTINUE
C
C     COMPLETED THE CASE OF TEMSTR .GT. TFT
C     CHECK TERMINATION VARIABLES
C
      IF ( TNL-TUNNEL)505,505,506
  506 IF(MAXSHT-NSHIFT) 510,510,515
  515 IF ( TIMAX-CTIME) 511,511,999
  505 PRINT 507
  507 FORMAT(1H1,'SIMULATION WAS TERMINATED BY THE MAXIMUM ADVANCE OF TH
     $E TUNNEL'//)
      GO TO 520
  510 PRINT 512
  512 FORMAT (1H1,'SIMULATION WAS TERMINATEDBY THE MAXIMUM NUMBER OF SHI
     $FTS'//)
      GO TO 520
  511 PRINT 513
  513 FORMAT ( 1H1,'SIMULATION WAS TERMINATED BY THE MAXIMUM CLOCK TIME
     $'//)
  520 PRINT 521
  521 FORMAT(5X,'**********SIMULATION SUMMARY DATA**********'//)
```

```
C
C      PRINT THE SUMMARY OF THE SIMULATION
C
       CTIME=CTIME/60.0
       WAITM=WAITM/60.0
       TBIT5=TBIT5/60.0
       TBIT1=TBIT1/60.0
       TBIT2=TBIT2/60.0
       TBIT3=TBIT3/60.0
       TBIT4=TBIT4/60.0
       TMOLE1=TMOLE1/60.0
       TMOLE2=TMOLE2/60.0
       TMOLE3=TMOLE3/60.0
       THIRD1=THIRD1/60.0
       THIRD2=THIRD2/60.0
       THIRD3=THIRD3/60.0
       TSUPPT=TSUPPT/60.0
       SWTTIM=SWTTIM/60.0
       PRINT 525
  525 FORMAT (1X,'CLOCK TIME',3X,'NO. SHIFT',3X,'TUNNEL LENGTH',3X,
     $ 'MH ON REST',3X,'IDLE TIME',2X,'BIT INSP HR' //)
       PRINT 526, CTIME,NSHIFT,TUNNEL,RESTMH,WAITM,TBIT5
  526 FORMAT(1X,F10.3,6X,I5,4X,F10.3,6X,F10.3,2X,F9.2,2X,F10.3 ///)
       PRINT 527
  527 FORMAT (13X,'HR WORKED',3X,'HR WAITED',3X,'DOWN TIME',3X,
     $ 'REPLACING HR' //)
       PRINT 528, TBIT1,TBIT2,TBIT3,TBIT4
  528 FORMAT ( 10H BIT       , 3F12.3, 3X, F12.3)
       PRINT 530, TMOLE1,TMOLE2,TMOLE3
  530 FORMAT ( 10H MOLE      , 3F12.3)
       PRINT 531,THIRD1,THIRD2,THIRD3
  531 FORMAT(10H THIRD     , 3F12.3)
       PRINT 897, TSUPPT,SWTTIM
  897 FORMAT (' TOTAL SUPPORTING TIME=', F12.3/' ',' TOTAL TIME DELAYE
     $BY THE SLOWER SUPPORTING SYSTEM=', F12.3)
       IDEOS=1
C
       CALL TRANS
C
       STOP
       END

COMPILATION:         NO  DIAGNOSTICS.
```

```
      SUBROUTINE CALCUM(ICF,X)
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,D1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWTID,TTM,TNL,TIMAX,NRBG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),IPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CI(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE

C
C     SUBROUTINE CALCUM DETERMINES AN ABSCISSA VALUE ON A CUMULATIVE
C      PROBABILITY CURVE CORRESPONDING TO A GIVEN RANDOM NUMBER
C      BETWEEN 0.0 AND 1.0
C
      I=ICF
      Y=RAND(N)
      JN=NCLAS(I)
      DO 100 J=1,JN
      IF (CF(I,J) .LE. Y .AND. CF(I,J+1) .GE. Y) GO TO 102
  100 CONTINUE
      PRINT 103, I,Y,JN
  103 FORMAT (1X,'I Y JN AT 103 IN CALCUM', I5, F10.8, I10)
      PRINT 111
  111 FORMAT (1X,'RUN TERMINATED BY ERROR IN SEARCHING THROUGH THE CF(I,
     $J)')
      IF ( JN .GE. 100 ) GO TO 113
      PRINT 112 ( CF(I,J), J=1,JN)
  112 FORMAT ( 3F18.8)
  113 STOP
  102 X=TV(I,J)+(TV(I,J+1)-TV(I,J))*((Y-CF(I,J))/(CF(I,J+1)-CF(I,J)))
      RETURN
      END

COMPILATION:        NO  DIAGNOSTICS.
```

```
C
      SUBROUTINE SUPPRT ( TFTA,REQMH )
C
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,D1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWIID,TTM,TNL,TIMAX,NRBG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),TPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CT(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE



C
C     SUBROUTINE SUPPRT DETERMINES THE MANHOURS OF TIME REQUIRED TO
C       COMPLETE THE SUPPORT WORK FOR ONE UNIT OF ADVANCE OF THE TUNNEL
C
      SPMH=0.0
      REQMH=0.0
      NFTR=INT(TFTA+0.4)
      IF ( NFTR .EQ. 0) GO TO 100
      DO 10 I=1,NFTR
      Y=RAND(N)
      DO  20 J=1,NRBG
   20 IF ( CFR(J) .LE. Y  .AND. CFR(J+1) .GE. Y ) GO TO 30
      PRINT 21
   21 FORMAT(1X,'CFR(I)-FTA(I) DIAGRAM HAS INCORRECT INPUT DATA')
      STOP
   30 SPMH=FTA(J)+(FTA(J+1)-FTA(J))*((Y-CFR(J))/(CFR(J+1)-CFR(J)))
   10 REQMH=REQMH+SPMH
  100 RETURN
      END

COMPILATION:        NO  DIAGNOSTICS.
```

```
      SUBROUTINE MOTION(NL,NS)
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,D1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWTID,TTM,TNL,TIMAX,NRBG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),TPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CT(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE
C
C     SUBROUTINE MOTION MOVES A TRAIN FROM ONE SWITCH TO THE NEXT
C
      DIMENSION SGL(10),MSS(10),GREV(100),DREV(100),DSREV(10)
C
C     REVERSE PERTINENT VARIABLES FOR LOADED TRAINS
C
      IF ( LOAD(NL) .EQ. 0) GO TO 100
      NNN=0
      IF ( D(NSECS)-DELTH) 815,816,816
  815 NSECS=NSECS-1
      NNN=1
  816 DO 101 I=1,NSECS
      IREV=NSECS-(I-1)
      GREV(IREV)=-G(I)
  101 DREV(IREV)=D(I)
      DO 99 I=1,NSECS
      G(I)=GREV(I)
   99 D(I)=DREV(I)
      DO 102 I=1,NSW
      J=NSW-(I-1)
  102 DSREV(I)=HAUL-DS(J)
      DO 98 I=1,NSW
   98 DS(I)=DSREV(I)
  100 SST=0.0
      SGL(1)=D(1)
      MSS(1)=1
      SGL(NSW)=0.0
      MSS(NSW)=0
      N9=NSW-1
      DO 103 I=2,N9
      DO 104 J=1,NSECS
      SST=SST+D(J)
      IF (SST-DS(I)) 104,106,107
  106 SGL(I)=D(J+1)
      MSS(I)=J+1
      GO TO 103
  107 SGL(I)=SST-DS(I)
      MSS(I)=J
```

```
      GO TO 103
  104 CONTINUE
  103 CONTINUE
      TIME(NL)=0.0
      TSTOP(NL)=0.0
      TPASS(NL)=0.0
      DSTOP(NL)=0.0
C
C     START LOCO IN MOTION
C
      IF ( LOAD(NL) .EQ. 0) GO TO 88
      JR=NSW-(NS-1)
      NS=JR
   88 SLEFT=DS(NS+1)-DS(NS)
      GLEFT=SGL(NS)
      MM=MSS(NS)
      FRFC=( FLOCO(NL)*WTLOC(NL)+( WTLOAD(NL)+WTCAR*NCARS)*FCAR)
      IF ( LOAD(NL) .EQ. 1) GO TO 777
      WTTRN(NL)=WTLOC(NL)+ NCARS*WTCAR
  777 GFC=( 20.0*G(MM))*WTTRN(NL)
      REQTF=FRFC+GFC
      IF ( SPEED(NL) ) 110,110,111
  110 AVATF=(T(NL,1)+T(NL,2))/2.0
  120 ACCFC=AVATF-REQTF
      ACCR=ACCFC*32.2/(WTTRN(NL)*2000.0)
      IF ( ACCR ) 115,116,117
  115 TD=0.0
      DD=0.0
      IF ( SPEED(NL)) 130,130,131
  130 IF (LOAD(NL) .EQ. 1) GO TO 132
      PRINT 133, NL,MM,G(MM),ACCR,WTLOC(NL),WTLOAD(NL),WTCAR,NCARS,FCAR,
     $WTTRN(NL),FLOCO(NL),FRFC,GFC,REQTF,AVATF,ACCFC,T(NL,1),T(NL,2)
  133 FORMAT ( 1H0,'LOCO NO.=', I3, 'WITHOUT LOAD CANNOT NEGOTIATE SECTI
     $ON NUMBER ',I4 /' ',3X,'GRADE=',F10.4,3X,'ACCR=',F12.4 /' ',
     $ 3F10.2, I5, 3F10.2 /' ',7F12.3)
      STOP
  132 PRINT 134, NL,MM,G(MM),ACCR,WTLOC(NL),WTLOAD(NL),WTCAR,NCARS,FCAR,
     $ WTTRN(NL),FLOCO(NL),FRFC,GFC,REQTF,AVATF,ACCFC,T(NL,1),T(NL,2)
  134 FORMAT ( 1H0,'LOCO=', I3,'WITH LOAD CANNOT NEGOTIATE SECTION NUMBE
     $R ',I4 /' ',3X,'REVERSED GRADE=',F10.4,3X,'ACCR=',F12.4 /' ',
     $ 3F10.2, I5, 3F10.2 /' ', 7F12.3)
      STOP
  131 IF ( GLEFT-SLEFT) 135,135,130
  135 IF ( SPEED(NL)-S(NL,2)) 136,136,137
  136 ADEC=-ACCR
      TTD=SPEED(NL)/ADEC
      TDD=SPEED(NL)*SPEED(NL)/(2.0*ADEC)
      TD=TD+TTD
      DD=TDD+DD
      IF ( DD-GLEFT) 130,130,138
  138 DTR=DD-GLEFT
      TD=TD-TTD
```

```
      DD=DD-TDD
      SP=SPEED(NL)
      ASA=SPEED(NL)*SPEED(NL)-2.0*ADEC*DTR
      IF ( ASA ) 261,261,262
  261 PRINT 263,ASA
  263 FORMAT (1X,'VARIABLE ASA IN MOTION HAS NEGATIVE SIGN', F10.3)
      STOP
  262 CONTINUE
      SPEED(NL)=SQRT(SPEED(NL)*SPEED(NL)-2.0*ADEC*DTR)
      TT1=(SP-SPEED(NL))/ADEC
      TD1=DTR
      D1=DD+TD1
      T1=TD+TT1
      GO TO 151
  137 ADEC=-ACCR
      SP=SPEED(NL)
      N7=KMAX-1
      DO 139 I=1,N7
      IF ( SPEED(NL)-S(NL,I)) 139,139,50
   50 IF ( SPEED(NL)-S(NL,I+1)) 140,140,139
  139 CONTINUE
      PRINT 141, SPEED(NL),NL
  141 FORMAT ( 1H0,'SPEED=',F10.3,'OF LOCO NUMBER',I3,'COULD NOT BE FOUN
     *D IN ITS CHARACTERISTIC CURVE')
      STOP
  140 KK=I
      TTD=( SPEED(NL)-S(NL,KK))/ADEC
      TDD=(SPEED(NL)*SPEED(NL)-S(NL,KK)*S(NL,KK))/(2.0*ADEC)
      TD=TD+TTD
      DD=DD+TDD
      IF (DD-GLEFT) 142,138,138
  142 SP=SPEED(NL)
      AVA1 =T(NL,KK)+(T(NL,KK+1)-T(NL,KK))*(SPEED(NL)-S(NL,KK))/
     *(S(NL,KK+1)-S(NL,KK))
      SPEED(NL)=S(NL,KK)
      AVATF=(AVA1+T(NL,KK))/2.0
      ACCFC=AVATF-REQTF
      ACCR=ACCFC*32.2/(WTTRN(NL)*2000.0)
      IF ( ACCR) 135,143,144
  144 IF ( ACCMAX-ACCR) 990,991,991
  990 ACCR=ACCMAX
  991 SPEED(NL)=S(NL,KK)+ACCR*(S(NL,KK+1)-S(NL,KK))/(ADEC+ACCR)
      TD1=(SPEED(NL)-S(NL,KK))/ADEC
      DD1=(SPEED(NL)*SPEED(NL)-S(NL,KK)*S(NL,KK))/(2.0*ADEC)
      TD=TD+TD1
      DD=DD+DD1
  143 TD2=(GLEFT-DD)/SPEED(NL)
      DD2=(GLEFT-DD)
      D1=DD+DD2
      T1=TD+TD2
      GO TO 151
```

```
C
C     CALCULATE THE CASE OF ZERO ACCELERATION
C
  116 IF ( SPEED(NL))130,130,145
  145 D1=GLEFT
      T1=GLEFT/SPEED(NL)
      SP=SPEED(NL)
      GO TO 151
C
C     CALCULATE THE CASE OF POSITIVE ACCELERATION
C

  117 IF ( ACCR-ACCMAX) 146,146,147
  147 ACCR=ACCMAX
  146 N7=KMAX-1
      DO 148 I=1,N7
      IF ( SPEED(NL)-S(NL,I)) 148,51,51
   51 IF ( SPEED(NL)-S(NL,I+1)) 150,148,148
  148 CONTINUE
      PRINT 149,NL,SPEED(NL)
  149 FORMAT ( 1H0,'LOCO NUMBER',I3,' HAD BAD INPUT DATA OF SPEED =',F10
     $.2)
      STOP
  150 KK=I
      T1=(S(NL,KK+1)-SPEED(NL))/ACCR
      D1=T1*(SPEED(NL)+(T1*(ACCR/2.0)))
      D2=GLEFT
      VV=SPEED(NL)*SPEED(NL)+2.0*ACCR*D2
      T2=(SQRT(VV)-SPEED(NL))/ACCR
      IF ( D1-D2) 351,152,152
  152 D1=D2
      T1=T2
      SP=SPEED(NL)
      SPEED(NL)=SP+T1*ACCR
      GO TO 151
  351 SP=SPEED(NL)
      SPEED(NL)=S(NL,KK+1)
  151 DSTOP(NL)=SPEED(NL)*SPEED(NL)/(2.0*DECEL)
  153 DISTR(NL)=DISTR(NL)+D1
      TIME(NL)=TIME(NL)+T1
      GLEFT=GLEFT-D1
      SLEFT=SLEFT-D1
      IF ( SLEFT-0.5 ) 154,154,507
  507 IF ( GLEFT-0.5 ) 156,156,157
  156 MM=MM+1
      GLEFT=D(MM)
      GFC=(20.0*G(MM))*WTTRN(NL)
      REQTF=FRFC+GFC
  111 CONTINUE
  157 IF ( SLEFT-GLEFT) 501,501,500
  501 IF ( DSTOP(NL)-SLEFT) 502,503,154
  502 IF ( SPEED(NL)-VELMAX) 506,505,505
  505 D1=SLEFT-DSTOP(NL)
      SPEED(NL)=VELMAX
```

```
      T1=D1/SPEED(NL)
      TIME(NL)=TIME(NL)+T1
      DISTR(NL)=DISTR(NL)+D1
  503 TSTOP(NL)=SPEED(NL)/DECEL
      TPASS(NL)=DSTOP(NL)/SPEED(NL)
      GO TO 405
  506 GLEFT=SLEFT
      GO TO 500
  500 CONTINUE
      IF ( SPEED(NL)-VELMAX) 158,216,216
  216 SPEED(NL)=VELMAX
      GO TO 116
  158 DO 159 K=1,KMAX
      IF ( SPEED(NL)-S(NL,K)) 159,52,52
   52 IF ( SPEED(NL)-S(NL,K+1)) 160,159,159
  159 CONTINUE
      PRINT 161, NL, SPEED(NL),(S(NL,K), K=1,KMAX)
  161 FORMAT ( 2H0,'LOCO NUMBER',I3,' AT SPEED =',F10.3,'HAD BAD INPUT D
     $ATA AND STOPPED'/' ',F12.3)
      STOP
  160 KK=K
      AVA1 =T(NL,KK)+(T(NL,KK+1)-T(NL,KK))*(SPEED(NL)-S(NL,KK))/
     $(S(NL,KK+1)-S(NL,KK))
      AVATF=(AVA1+T(NL,KK+1))/2.0
      GO TO 120
  154 SLEFT=D1+SLEFT
      OTRD=(D1+DSTOP(NL))-SLEFT
      IF ( ACCR ) 400,401,400
  401 D1=D1-OTRD
      DISTR(NL)=DISTR(NL)-OTRD
      TIME  (NL)=TIME(NL)-T1
      T1=D1/SPEED(NL)
      TIME(NL)=TIME(NL)+T1
      TSTOP(NL)=SPEED(NL)/DECEL
      TPASS(NL)=DSTOP(NL)/SPEED(NL)
      GO TO 405
  400 V2=(2.0*SLEFT+SP*SP/ACCR)*(ACCR*DECEL/(ACCR+DECEL))
      IF ( V2 ) 411,412,412
  411 PRINT 413, V2,SP,SPEED(NL),ACCR,SLEFT,D1,DSTOP(NL)
  413 FORMAT (1X,'V2 IN MOTION HAS NEGATIVE VALUE'/' ',2X,
     $ 7F10.3)
      STOP
  412 SPEED(NL)=SQRT(V2)
      DISTR(NL)=DISTR(NL)-D1
      TIME  (NL)=TIME(NL)-T1
      DSTOP(NL)=SPEED(NL)*SPEED(NL)/(2.0*DECEL)
      D1=(SPEED(NL)*SPEED(NL)-SP*SP)/(2.0*ACCR)
      DISTR(NL)=DISTR(NL)+D1
      T1=(SPEED(NL)-SP)/ACCR
      TIME(NL)=TIME(NL)+T1
  155 TSTOP(NL)=SPEED(NL)/DECEL
      TPASS(NL)=DSTOP(NL)/SPEED(NL)
  405 IF ( LOAD(NL) .EQ. 0) GO TO 455
```

```
      NS=NSW-NS+1
      DO 861 I=1,NSECS
      IREV=NSECS-(I-1)
      GREV(IREV)=-G(I)
  861 DREV(IREV)=D(I)
      DO 862 I=1,NSECS
      G(I)=GREV(I)
  862 D(I)=DREV(I)
      DO 863 I=1,NSW
      J=NSW-(I-1)
  863 DSREV(I)=HAUL-DS(J)
      DO 864 I=1,NSW
  864 DS(I)=DSREV(I)
      IF ( NNN .EQ. 0) GO TO 455
      NSECS=NSECS+1
  455 RETURN
      END

COMPILATION:          NO  DIAGNOSTICS.

      SUBROUTINE LOADNG(NL)
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,D1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWIID,TTM,TNL,TIMAX,NRBG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),TPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CT(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE
C
C     SUBROUTINE LOADNG SIMULATES THE LOADING OF THE TRAIN
C
      TLOAD(NL)=0.0
      WTLOAD(NL)=0.0
      Y=RAND(N)
      N6=NSC-1
      DO 60 K=1,N6
   60 IF ( CFS(K) .LT. Y .AND. CFS(K+1) .GE. Y ) GO TO 61
      PRINT 62
   62 FORMAT ( 2X,'STOPPED BY AN ERROR IN SEARCHING THROUGH CFS(I)')
      STOP
   61 TSW=ST(K)+(ST(K+1)-ST(K))*((Y-CFS(K))/(CFS(K+1)-CFS(K)))
      TLOAD(NL)=TMUCK+TSW
      WTLOAD(NL)=WTMUCK
      WTTRN(NL)=WTLOAD(NL)+NCARS*WTCAR+WTLOC(NL)
      LOAD(NL)=1
      RETURN
      END

COMPILATION:          NO  DIAGNOSTICS.
```

```
      SUBROUTINE DUMP(NL)
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,D1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWTID,TTM,TNL,TIMAX,NRRG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),IPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CT(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE
C
C     SUBROUTINE DUMP SIMULATES THE DUMPING OF THE TRAIN
C
      Y=RAND(N)
      N5=NDC-1
      DO 100 J=1,N5
  100 IF ( CFD(J) .LT. Y .AND. CFD(J+1) .GE. Y) GO TO 110
      PRINT 120,Y, ( CFD(J), J=2,NDC)
  120 FORMAT (1H0,'IN DUMPING CYCLE RAND=',F10.6, 2X,'CANNOT BE FOUND'
     $/' ', 3F10.6)
      STOP
  110 TDUMP(NL)=CT(J)+(CT(J+1)-CT(J))*((Y-CFD(J))/(CFD(J+1)-CFD(J)))
      LOAD(NL)=0
      RETURN
      END
```

COMPILATION: NO DIAGNOSTICS.

```
      SUBROUTINE MUCK
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,D1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWTID,TTM,TNL,TIMAX,NRBG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),IPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CT(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE


C
C     SUBROUTINE MUCK DETERMINES THE WEIGHT OF THE MUCK LOADED INTO THE
C      CARS
C
      AFT=0.0
      TMUCK=0.0
      WTMUCK=0.0
      N3=LCLAS-1
      DO 10 I=1,NCARS
      Y=RAND(N)
      DO 20 J=1,N3
   20 IF(CFL(J) .LT. Y .AND. CFL(J+1) .GE. Y ) GO TO 30
      PRINT 25, Y
   25 FORMAT( 1H0,' IN THE LOADING CYCLE RAND=', F10.6,2X,'CANNOT BE FOU
     $ND IN CFL(I)')
      PRINT 26 ( CFL(K), K=1,LCLAS)
   26 FORMAT ( F12.6)
      STOP
   30 WTMM=WTL(J)+(WTL(J+1)-WTL(J))*((Y-CFL(J))/(CFL(J+1)-CFL(J)))
   10 WTMUCK=WTMUCK+WTMM
      TPM=ADRT*CROSEC*GAMMA/(60.0*2000.0)
      TMUCK=WTMUCK/TPM
      AFT=ADRT*TMUCK/60.0
      RETURN
      END

COMPILATION:           NO  DIAGNOSTICS.
```

```
      SUBROUTINE TRANS
      DIMENSION CFMS(15),TMS(15),CFMD(15),TMD(15)
      DIMENSION LLW(10) ,LC(10)
      DIMENSION TLOC2(10),TLOC3(10),TLOC4(10),
     $LW(10),IA(10),IDE(10),IDL(10)
      COMMON WTMUCK,WTIM,NLOCO,TMUCK,KMAX,NCARS,LCLAS,NDC,ACCMAX,
     $VELMAX,DECEL,NSC,D1,AFT,HAUL,NSECS,NSW,WTCAR,FCAR,TPM,ADRT,
     $CROSEC,GAMMA,CTIME,LWTID,TTM,TNL,TIMAX,NRHG,ILS,
     $CFR(13),FTA(13),NCLAS(120),LL(10),CTLOC(10),TLOC1(10),WTLOC(10),
     $FLOCO(10),G(100),D(100),DS(10),WTLOAD(10),SPEED(10),LOAD(10),
     $DISTR(10),TIME(10),TSTOP(10),TPASS(10),WTTRN(10),CFL(13),CFD(13),
     $CT(13),WTL(13),DSTOP(10),ST(13),CFS(13),TLOAD(10),TDUMP(10),
     $ CF(120,13),TV(120,13),T(10,30),S(10,30),LS(20),ILWTID
     $,IDLOAD,SCCTM,TBIT2,TMOLE2,THIRD2,DELTH,IDEOS,TNLT
     $,FTAD,TMOLE1,TBIT1,THIRD1,NCREW,SHFTMH,HRPSH,NSHIFT,IMAN,ICYCLE
C
C     SUBROUTINE TRANS CONTROLS THE SIMULATION OF THE MATERIALS HANDLING
C      SUBSYSTEM
C
C     READ IN CONTROL CARDS
C
      IF ( ICYCLE .NE. 0) GO TO 650
      IF ( IDEOS .EQ. 1) GO TO 699
      IF ( ILS .NE. 0) GO TO 652
C
C     READ IN INPUT DATA FOR CONTINUOUS MATERIAL HANDLING SYSTEM
C
      READ 653, EFFCSA,FLUVEL,GMUCK
  653 FORMAT ( 3F10.3)
      READ 654, NCPTS
  654 FORMAT ( I5)
      READ 655 ( CFMS(I),TMS(I) , I=1,NCPTS)
  655 FORMAT ( 6F10.3)
      READ 654, NCST
      READ 655 ( CFMD(I),TMD(I), I=1,NCST)
C
C
C     INITIALIZE VARIABLES TO ZERO
C
      SPWT=0.0
      TBELT1=0.0
      TBELT2=0.0
      TBELT3=0.0
      DWNTM=0.0
      SUMDLY=0.0
C
C     CALCULATE PWT AND SPWT
C
      Y=RAND(N)
      DO 656 I=1,NCPTS
  656 IF ( CFMS(I) .LT. Y  .AND. CFMS(I+1) .GE. Y) GO TO 657
```

```
      PRINT 658, Y
  658 FORMAT (1X,'RAND=', F12.6,3X,'CANNOT BE FOUND IN CFMS-TMS CURVE')
      STOP
  657 PWT=TMS(I)+(TMS(I+1)-TMS(I))*((Y-CFMS(I))/(CFMS(I+1)-CFMS(I)))
      PWT=PWT*60.0
      SPWT=SPWT+PWT
      IF ( ILS .EQ. 0) GO TO 701
      PRINT 28
   28 FORMAT ( '  ILS WAS NOT ZERO')
      STOP
  652 CAPMH=EFFCSA*FLUVEL*GMUCK/2000.0
      TPM=ADRT*CROSEC*GAMMA/(60.0*2000.0)
      MOTM=FTAD*60.0/ADRT
      IF ( CAPMH-TPM) 659,660,660
C
C     COUNT TIME DELAYED AND MH WAITED DUE TO HANDLING SYSTEM
C
  659 ADJTPM=CAPMH
      AMOTM=MOTM*TPM/ADJTPM
      DIFTM=AMOTM-MOTM
      SUMDLY=SUMDLY+DIFTM
      CTIME =CTIME+DIFTM
      TBELT1=TBELT1+DIFTM
      TBIT1=TBIT1+DIFTM
      TMOLE1=TMOLE1+DIFTM
      THIRD1=THIRD1+DIFTM
      DIFMH=DIFTM*NCREW/60.0
  677 IF ( SHFTMH-DIFMH) 675,676,676
  675 SHFTMH=SHFTMH+NCREW*HRPSH
      NSHIFT=NSHIFT+1
      GO TO 677
  676 SHFTMH=SHFTMH-DIFMH
      TBELT2=TBELT2+DIFTM
      MOTM=AMOTM
  660 IF ( SPWT-MOTM) 661,662,662
  661 MOTM=MOTM-SPWT
      TBELT1=TBELT1+SPWT
      SPWT=0.0
C
C     MH FOR REPAIR
C
      Y=RAND(N)
      DO 663 J=1,NCST
  663 IF ( CFMD(J) .LT. Y .AND. CFMD(J+1) .GE. Y) GO TO 664
      PRINT 665, Y
  665 FORMAT ( 1X,'RAND=', F12.5,3X,'NEVER BE FOUND IN CFMD-TMD')
      STOP
  664 DWNMH=TMD(J)+(TMD(J+1)-TMD(J))*((Y-CFMD(J))/(CFMD(J+1)-CFMD(J)))
C
C     CALCULATE DOWNTIME
C
```

```
  663 IF ( SHFTMH-DWNMH) 666,667,667
  666 DWNMH=DWNMH-SHFTMH
      IF ( IMAN .EQ. 0) GO TO 856
      DWNTM=SHFTMH*60.0/IMAN+DWNTM
  856 SHFTMH=NCREW*HRPSH
      NSHIFT=NSHIFT+1
      IMAN=NCREW
      GO TO 668
C
C     DETERMINE TBELT1 AND WAITING TIMES
C
  667 SHFTMH=SHFTMH-DWNMH
      DWNTM=DWNTM+DWNMH*60.0/IMAN
      TBELT3=TBELT3+DWNTM
      CTIME=CTIME+DWNTM
      TBIT2=TBIT2+DWNTM
      TMOLE2=TMOLE2+DWNTM
      THIRD2=THIRD2+DWNTM
      DWNTM=0.0
C
C     CALCULATE PWT AND SPWT
C
      Y=RAND(N)
      DO 669 I=1,NCPTS
  669 IF ( CFMS(I) .LT. Y .AND. CFMS(I+1) .GE. Y ) GO TO 670
      PRINT 658, Y
      STOP
  670 PWT=TMS(I)+(TMS(I+1)-TMS(I))*((Y-CFMS(I))/(CFMS(I+1)-CFMS(I)))
      PWT=PWT*60.0
      SPWT=SPWT+PWT
      GO TO 660
  662 SPWT=SPWT-MOTM
      TBELT1=TBELT1+MOTM
      MOTM=0.0
      GO TO 701
C
C     PRINT SUMMARY OF CONTINUOUS MATERIAL HANDLING SYSTEM
C
  699 PRINT 672
  672 FORMAT ( 1H0,' SUMMARY OF CONTINUOUS SYSTEM')
      TBELT1=TBELT1/60.0
      TBELT2=TBELT2/60.0
      TBELT3=TBELT3/60.0
      SUMDLY=SUMDLY/60.0
      PRINT 673
  673 FORMAT ( 1H0,'  WORK TIME   TIME DELAYED     DOWN TIME')
      PRINT 674, TBELT1,TBELT2,TBELT3
  674 FORMAT ( 3F12.3)
      PRINT 685, SUMDLY
  685 FORMAT (1X,'TOTAL TIME DELAYED BY THE CONTINUOUS MATERIAL HANDLING
     $ SYSTEM', F12.3)
      GO TO 701
```

```
C
C     CYCLIC MATERIAL HANDLING SYSTEM
C
  650 IF ( IDEOS .EQ. 1) GO TO 299
      IDLC=0
      ILC=0
      DO 50 I=1,NLOCO
   50 LC(I)=0
      IF ( ILS .EQ. 0) GO TO 99
      IF ( ILWTID .EQ. 1) GO TO 90
   98 IF ( LWTID .NE. 0) GO TO 301
      WTIM=0.0
      GO TO 301
   99 READ 100,NLOCO,KMAX,NSECS,NSDP,NCARS,LCLAS,NDC ,NSC
  100 FORMAT(8I5)
      PRINT 101,NLOCO,NSECS,NCARS
  101 FORMAT (1H1,3X,'NUMBER OF LOCOMOTIVES =',I5 /'0',3X,
     $'NUMBER OF GRADE SECTIONS =',I5 /'0',3X,'NUMBER OF CARS PER TRAIN
     $=', I5 //)
C
C     READ IN ALL CHARACTERISTIC CURVES OF LOCOMOTIVES
C
      READ 102 ((T(I,J),S(I,J), J=1,KMAX), I=1,NLOCO)
  102 FORMAT ( 6F10.3)
C
C     READ IN THE CUMULATIVE FREQUENCY CURVES OF LOADING AND DUMPING
C
      READ 103 ( CFL(I),WTL(I), I=1,LCLAS)
      READ 103 ( CFS(I), ST(I), I=1,NSC)
      READ 103 ( CFD(I), CT(I), I=1,NDC)
  103 FORMAT( 6F10.3)
C
C     READ IN THE WEIGHT AND FRICTION COEFFICIENT OF THE LOCOMOTIVES
C
      READ 103 (WTLOC(I),FLOCO(I), I=1,NLOCO)
C
C     READ IN THE PROFILE OF THE TUNNEL
C
      READ 103 ( G(I),D(I), I=1,NSECS)
C
C     READ IN THE WEIGHT AND FRICTION COEFFICIENT OF THE CARS
C
      READ 103 , WTCAR,FCAR
C
C     READ IN SPEED LIMITATIONS
C
      READ 103, ACCMAX,VELMAX,DECEL
C
C     READ IN THE DISTANCE BETWEEN SWITCHES, DELTH, AND THE NUMBER OF
C      SWITCHES BETWEEN THE DUMPING STATION AND THE PORTAL
C
```

```
      READ 104, DISW,DELTH
  104 FORMAT ( 2F10.3, I5)
C
C     INITIALIZE VARIABLES
C
      DO 105 I=1,NLOCO
      DISTR(I)=0.0
      LOAD(I)=0
      WTLOAD(I)=0.0
      WTTRN(I)=0.0
      TLOC1(I)=0.0
      TLOC2(I)=0.0
      TLOC3(I)=0.0
      TLOC4(I)=0.0
      TIME(I)=0.0
      CTLOC(I)=0.0
      SPEED(I)=0.0
      TPASS(I)=0.0
      TSTOP(I)=0.0
      DSTOP(I)=0.0
  105 CONTINUE
      LIL=0
      NLDE=0
      NLDL=0
      HAUL=0.0
      TSEC=0.0
      NSW=0
      SAFT=0.0
      WTD=0.0
      WTG=0.0
C
C     LOCATE AND COUNT THE SWITCH POINTS
C
      DO 106 J=1,NSDP
  106 HAUL=HAUL+D(J)
      TNLT=TNL+HAUL
      NSW=2
      DH=HAUL
  109 IF ( DH-DISW) 107,108,108
  108 NSW=NSW+1
      DH=DH-DISW
      GO TO 109
  107 NN=NSW-1
      DMS=DH
      IF ( NN .EQ. 1) GO TO 110
      DO 111 I=2,NN
  111 DS(I)=DISW*(I-1)
  110 DS(1)=0.0
      DS(NSW)=HAUL
```

```
C
C     COUNT THE NUMBER OF SECTIONS AT THE START OF THE SIMULATION AND
C      DETERMINE THE DISTANCE TO THE LAST SECTION
C
      NSECS=NSDP+1
      DU=D(NSECS)
      D(NSECS)=0.0
C
C     LOCATE THE LOCOMOTIVES AT THE STARTING POINT
C
      DO 199 I=1,NLOCO
  199 IDE(I)=0
      NLDE=0
      NLDL=0
      IF ( NLOCO-NSW) 311,112,113
  311 NWLD=0
      N2=NSW-NLOCO +1
      DO 114 I= NSW,N2,-1
      J=NSW-I+1
      LS(I)=2
  114 LL(I)=J
      N1=N2-1
      DO 115 I=1,N1
  115 LS(I)=0
      GO TO 116
  112 NWLD=1
      IDE(NLOCO)=1
      NLDE=1
      DO 117 I=1,NSW
      J=NSW-I+1
      LS(I)=2
  117 LL(I)=J
      GO TO 116
  113 NWLD=NLOCO-NSW+1
      LMN=0
      DO 312 I=NSW,NLOCO
      LMN=LMN+1
  312 IDE(I)=LMN
      NLDE=NWLD
      DO 118 I=1,NSW
      J=NSW-I+1
      LS(I)=2
  118 LL(I)=J
      NEX=NSW+1
      DO 97 I=NEX,NLOCO
   97 LL(I)=1
  116 CONTINUE
      DO 120 I=1,NLOCO
  120 IDL(I)=0
      IF ( ILS .EQ. 0) GO TO 701
```

```
C
C     START THE SIMULATION WITH LOCOMOTIVE NUMBER 1 AT THE LOADING POINT
C
C
   90 NL=1
C
      CALL LOADNG(NL)
C
      IDLOAD=1
      CCTM=WTLOAD(NL)*2000.0*60.0/(CROSEC*GAMMA*ADRT)
      SCCTM=SCCTM+CCTM
      TLOC1(NL)=TLOC1(NL)+TLOAD(NL)
      CTLOC(NL)=CTLOC(NL)+TLOAD(NL)
      SAFT=SAFT+AFT
      WTG=WTG+WTLOAD(NL)
      NS=LL(NL)
      LS(NS)=1
C
C     DETERMINE THE LOADING TIME FOR THE LOCOMOTIVE
C
      DO 119 J=2,NLOCO
      TLOC4(J)=TLOAD(NL)
  119 CTLOC(J)=TLOAD(NL)
C
      CALL MOTION(NL,NS)
C
      CTLOC(NL)=CTLOC(NL)+TIME(NL)/60.0
      TLOC3(NL)=TLOC3(NL)+TIME(NL)/60.0
      IF (LOAD(NL) .EQ. 1) GO TO 120
      LS(NS)=LS(NS)-2
      NS=NS+1
      LL(NL)=NS
      LS(NS)=LS(NS)+2
      NS1=NS-1
      NS2=NS
      GO TO 121
  120 LS(NS)=LS(NS)-1
      NS=NS-1
      LL(NL)=NS
      LS(NS)=LS(NS)+1
      NS1=NS+1
      NS2=NS
  121 CONTINUE
      IF ( LOGPRT .NE. 0 ) GO TO 301
      PRINT 411
  411 FORMAT ( 1H0, 'LOCO NO.  CLOCK TIME  MOVING SW NO.   LOAD'/' ',25X
     $,'FROM   TO'  /)
      PRINT 412, NL,CTLOC(NL),NS1,NS2,LOAD(NL)
  412 FORMAT ( 4X,I3,4X,F10.2,5X,I2,4X,I2,7X,I1 //)
C
```

```
C       CHOOSE THE LOCOMOTIVE HAVING THE SMALLEST VALUE OF CTLOC(I)
C
  301 IL=0
      M=1
      DO 122 J=2,NLOCO
  122 IF(CTLOC(M) .GT. CTLOC(J)) M=J
      NL=M
C
C       EMPTY TRAIN
C
      IF ( LIL .EQ. 0) GO TO 200
      DO 221 I=1,LIL
  221 IF ( NL .EQ. LLW(I)) GO TO 222
      GO TO 200
  222 M=I
      IF ( LLW(M) .EQ. LIL) GO TO 224
      LLW(M)=0
      M1=M+1
      DO 223 J=M1,LIL
      K=J-1
  223 LLW(K)=LLW(J)
  224 LIL=LIL-1
  200 IF ( LOAD(NL) .EQ. 1) GO TO 123
      NS=LL(NL)
      IF ( NS .EQ. NSW) GO TO 124
      IF ( NS .EQ. 1) GO TO 125
      IF ( LS(NS+1) .EQ. 2 .OR. LS(NS+1) .EQ. 3) GO TO 360
      GO TO 361
  360 IF ( ILC .EQ. 0) GO TO 129
      NSS=NS+1
      DO 362 I=1,NLOCO
  362 IF ( LL(I) .EQ. NSS ) GO TO 363
      PRINT 364, NSS
  364 FORMAT ( ' NSS AT 364 IN TRANS', I5)
      STOP
  363 II=I
      IF ( LOAD(II) .EQ. 0) GO TO 366
      J1=II+1
      DO 365 K=J1,NLOCO
  365 IF ( LL(K) .EQ. NSS) GO TO 367
      PRINT 364, NSS
      STOP
  367 II=K
  366 DO 368 I=1,ILC
  368 IF ( LC(I) .EQ. II) GO TO 369
      GO TO 129
  369 ILC=ILC+1
      LC(ILC)=NL
      IDLC=1
      GO TO 129
```

```
  361 CTLOC(NL)=CTLOC(NL)+TPASS(NL)/60.0
      DISTR(NL)=DISTR(NL)+DSTOP(NL)
      TLOC3(NL)=TLOC3(NL)+TPASS(NL) /60.0
C
      CALL MOTION (NL,NS)
C
      IF ( LOAD(NL) .EQ. 1) GO TO 127
      LS(NS)=LS(NS)-2
      NS=NS+1
      LL(NL)=NS
      LS(NS)=LS(NS)+2
      NS1=NS-1
      NS2=NS
      GO TO 128
  127 LS(NS)=LS(NS)-1
      NS=NS-1
      LL(NL)=NS
      LS(NS)=LS(NS)+1
      NS1=NS+1
      NS2=NS
  128 CONTINUE
      CTLOC(NL)=CTLOC(NL)+TIME(NL)/60.0
      TLOC3(NL)=TLOC3(NL)+TIME(NL)/60.0
      IF ( LOGPRT .NE. 0) GO TO 413
      PRINT 411
      PRINT 412, NL,CTLOC(NL),NS1,NS2,LOAD(NL)
  413 IF (IL .EQ. 0) GO TO 300
      IF (LIL .EQ. 0 ) GO TO 225
      DO 192 I=1,IL
      DO 228 J=1,LIL
  228 IF ( LW(I) .EQ. LLW(J)) GO TO 229
      ATPS=0.0
      GO TO 230
  229 ATPS=FTPS
  230 JJ=LW(I)
      CTLOC(JJ)=CTLOC(JJ)+ATPS+TIME(NL)/60.0
  192 TLOC4(JJ)=TLOC4(JJ)+ATPS+TIME(NL)/60.0
      DO 231 I=1,IL
      DO 232 J=1,LIL
  232 IF ( LW(I) .EQ. LLW(J)) GO TO 231
      LIL=LIL+1
      LLW(LIL)=LW(I)
  231 CONTINUE
      FTPS=TSTOP(NL)/60.0
      DO 35 I=1,IL
   35 LW(I)=0
      IL=0
      GO TO 300
  225 DO 226 I=1,IL
      JJ=LW(I)
      CTLOC(JJ)=CTLOC(JJ)+TIME(NL)/60.0
  226 TLOC4(JJ)=TLOC4(JJ)+TIME(NL)/60.0
```

```
      LIL=IL
      FIPS=TSTOP(NL)/60.0
      DO 227 I=1,LIL
  227 LLW(I)=LW(I)
      DO 36 I=1,IL
   36 LW(I)=0
      IL=0
      LW(I)=0
      GO TO 300
  124 IF ( LS(NS) .EQ. 3 .OR. LS(NS) .EQ. 1) GO TO 338
      GO TO 339
  338 IF ( ILC .EQ. 0) GO TO 129
      DO 331 I=1,NLOCO
  331 IF ( LL(I) .EQ. NS .AND. LOAD(I) .EQ. 1) GO TO 332
      PRINT 541
  541 FORMAT ( 1X,'STOPPED AT 541 IN TRANS')
      STOP
  332 INLC=I
      DO 333 I=1,ILC
  333 IF ( LC(I) .EQ. INLC) GO TO 334
      GO TO 129
  334 ILC=ILC+1
      LC(ILC)=NL
      IDLC=1
      GO TO 129
  339 CTLOC(NL)=CTLOC(NL)+TSTOP(NL)/60.0
      DISTR(NL)=DISTR(NL)+DSTOP(NL)
      TLOC3(NL)=TLOC3(NL)+TSTOP(NL)/60.0+TIME(NL)/60.0
      SPEED(NL)=0.0
      TPASS(NL)=0.0
      TSTOP(NL)=0.0
      DSTOP(NL)=0.0
      TIME(NL)=0.0
C
C     CHECK THE TUNNEL LENGTH AND HAULAGE DISTANCE AND RELOCATE THE
C      LAST SWITCH
C
      IF ( SAFT .GE. DELTH ) GO TO 180
      GO TO 189
  180 SAFT=SAFT-DELTH
      HAUL=HAUL+DELTH
      TSEC=TSEC+DELTH
      DMS=DMS+DELTH
      IF ( TSEC-DD) 181,182,182
  182 TSEC=TSEC-DD
      D(NSECS)=DD
      NSECS=NSECS+1
      DD=D(NSECS)
  181 D(NSECS)=TSEC
      IF ( DMS-DISW ) 183,184,184
  184 DMS=DMS-DISW
```

```
      DS(NSW)=HAUL-DMS
      NSW=NSW+1
  183 DS(NSW)=HAUL
      IF ( HAUL-TNLT) 189,185,185
  185 PRINT 186
  186 FORMAT (1H0, 'TUNNELLING WAS COMPLETED AND SIMULATION TERMINATED')
      GO TO 299
  189 CONTINUE
      IF ( LWTID .NL. 0) GO TO 700
      WTIM=CTLOC(NL)-CTIME
      IF ( IL .EQ. 0) GO TO 701
      DO 702 I=1,IL
      JJ=LW(I)
      LW(I)=0
      CTC=CTLOC(NL)-CTLOC(JJ)
      CTLOC(JJ)=CTLOC(NL)
  702 TLOC4(JJ)=TLOC4(JJ)+CTC
      IL=0
      GO TO 701
  700 IF ( IDLOAD .EQ. 1) GO TO 600
      IDLOAD=1
C
      CALL LOADNG(NL)
C
      CCTM=WTLOAD(NL)*2000.0*60.0/(CROSEC*GAMMA*ADRT)
      SCCTM=SCCTM+CCTM
      WTG=WTG+WTLOAD(NL)
      CTLOC(NL)=CTLOC(NL)+TLOAD(NL)
      TLOC1(NL)=TLOC1(NL)+TLOAD(NL)
      LS(NS)=LS(NS)-1
      SAFT=SAFT+AFT
      IF ( IL .EQ. 0) GO TO 300
      DO 191 I=1,IL
      JJ=LW(I)
      LW(I)=0
      CTLOC(JJ)=CTLOC(JJ) +TLOAD(NL)
  191 TLOC4(JJ)=TLOC4(JJ) + TLOAD(NL)
      IL=0
      GO TO 300
  600 WWTM=(CTIME+SCCTM)-CTLOC(NL)
      IF ( WWTM ) 601,601,602
  601 IF ( IL .EQ. 0) GO TO 701
      DO 931 I=1,IL
      JJ=LW(I)
      LW(I)=0
      TLOC4(JJ)=TLOC4(JJ)+(CTLOC(NL)-CTLOC(JJ))
  931 CTLOC(JJ)=CTLOC(JJ)+(CTLOC(NL)-CTLOC(JJ))
      IL=0
      GO TO 701
  602 CTLOC(NL)=CTLOC(NL)+WWTM
      TLOC4(NL)=TLOC4(NL)+WWTM
      IF ( IL .EQ. 0) GO TO 300
```

```
      DO 39 I=1,IL
      JJ=LW(I)
      LW(I)=0
      CTLOC(JJ)=CTLOC(JJ)+WWTM
   39 TLOC4(NL)=TLOC4(NL)+WWTM
      IL=0
      GO TO 300
  129 CTLOC(NL)=CTLOC(NL)+TSTOP(NL)/60.0
      DISTR(NL)=DISTR(NL)+DSTOP(NL)
      TLOC3(NL)=TLOC3(NL)+TSTOP(NL)/60.0
      SPEED(NL)=0.0
      TPASS(NL)=0.0
      TSTOP(NL)=0.0
      DSTOP(NL)=0.0
      TIME(NL)=0.0
      IF ( IDLC .NE. 1) GO TO 150
      IDLC=0
      SSCC=CTTM-CTLOC(NL)
      IF ( SSCC) 335,335,336
  336 CTLOC(NL)=CTLOC(NL)+SSCC
      TLOC4(NL)=TLOC4(NL)+SSCC
  335 IF ( IL .EQ. 0) GO TO 340
      DO 337 I=1,IL
      JJ=LW(I)
      LW(I)=0
      TLOC4(JJ)=TLOC4(JJ)+(CTLOC(NL)-CTLOC(JJ))
      CTLOC(JJ)=CTLOC(JJ)+(CTLOC(NL)-CTLOC(JJ))
      ILC=ILC+1
  337 LC(ILC)=JJ
      IL=0
      GO TO 340
  150 IL=IL+1
      LW(IL)=NL
      IF(IL .EQ. 1) GO TO 130
C
C     ARRANGE LW(IL) IN ASCENDING ORDER
C
      DO 131 I=1,IL
  131 IA(I)=LW(I)
      NA=IL-1
      DO 132 J=1,NA
      M=J
      MA=J+1
      DO 133 I=MA,IL
  133 IF ( IA(I) .LT. IA(M)) M=I
      ITEMP=IA(J)
      IA(J)=IA(M)
  132 IA(M)=ITEMP
C
C     SEARCH FOR THE SHORTEST VALUE OF CTLOC(I) EXCEPT FOR CTLOC(IL)
C
      ML=1
      N1=2
```

```
      DO 134 I=1,IL
      NJ=IA(I)
      IF ( NJ .EQ. ML) GO TO 560
      NK=I
      GO TO 561
  560 ML=ML+1
      N1=ML+1
      IF ( I .NE. IL) GO TO 134
      IF ( ML .EQ. NLOCO) GO TO 139
      GO TO 581
  134 CONTINUE
  561 DO 562 J=NK,IL
      NJ=IA(J)
      IF ( N1 .EQ. NJ) GO TO 563
  135 N2=NJ-1
      DO 137 K=N1,N2
  137 IF ( CTLOC(ML) .GT. CTLOC(K)) ML=K
  563 N1=NJ+1
  562 CONTINUE
      IF ( NJ .EQ. NLOCO) GO TO 139
  581 DO 140 J=N1,NLOCO
  140 IF ( CTLOC(ML) .GT. CTLOC(J)) ML=J
  139 NL=ML
      GO TO 200
  130 NJ=LW(IL)
      IF ( NJ .EQ. 1) GO TO 141
      ML=1
      N1=2
      IF ( NJ .EQ. 2) GO TO 142
      N2=NJ-1
      DO 143 J=N1,N2
  143 IF ( CTLOC(ML) .GT. CTLOC(J)) ML=J
  142 N3=NJ+1
      N4=NLOCO
      IF ( NJ .EQ. NLOCO) GO TO 144
      DO 145 J=N3,N4
  145 IF ( CTLOC(ML) .GT. CTLOC(J)) ML=J
  144 NL=ML
      GO TO 200
  141 ML=2
      N1=3
      N2=NLOCO
      DO 246 J=N1,N2
  246 IF ( CTLOC(ML) .GT. CTLOC(J)) ML=J
      NL=ML
      GO TO 200
  125 IF ( NLDE .EQ. 1) GO TO 146
      IF ( IDE(NL) .EQ. 1) GO TO 146
      IF ( ILC .EQ. 0) GO TO 150
      N11=IDE(NL)-1
      DO 341 I=1,N11
      DO 342 J=1,NLOCO
```

```
342 IF ( IDE(J) .EQ. I) GO TO 343
    PRINT 344, I
344 FORMAT ( ' IDE(NL)=I AT 344 IN TRANS COULD NOT BE FOUND', I5)
    STOP
343 JNL=J
    DO 345 K=1,ILC
345 IF ( JNL .EQ. LC(K)) GO TO 346
    GO TO 341
346 ILC=ILC+1
    LC(ILC)=NL
    SSCC=CTTM-CTLOC(NL)
    CTLOC(NL)=CTLOC(NL)+SSCC
    TLOC4(NL)=TLOC4(NL)+SSCC
    IF ( IL .EQ. 0) GO TO 371
    DO 372 K=1,IL
    JJ=LW(K)
    LW(K)=0
    ILC=ILC+1
    LC(ILC)=JJ
    TLOC4(JJ)=TLOC4(JJ)+(CTTM-CTLOC(JJ))
372 CTLOC(JJ)=CTLOC(JJ)+(CTTM-CTLOC(JJ))
    IL=0
    GO TO 371
371 IF ( I .EQ. N11) GO TO 425
    N10=I+1
    GO TO 347
341 CONTINUE
    GO TO 150
347 DO 348 L=N10,N11
    DO 349 J=1,NLOCO
349 IF ( IDE(J) .EQ. L) GO TO 350
    PRINT 351, L
351 FORMAT ( 1X,'STOPPED AT 351 IN TRANS', I5)
    STOP
350 JJ=J
    TLOC4(JJ)=TLOC4(JJ)+( CTTM-CTLOC(JJ))
    CTLOC(JJ)=CTTM
    ILC=ILC+1
    LC(ILC)=JJ
348 CONTINUE
425 IF ( IDE(NL) .EQ. NLDE) GO TO 340
    N13=IDE(NL)+1
    DO 420 I=N13,NLDE
    DO 421 J=1,NLOCO
421 IF ( IDE(J) .EQ. I) GO TO 422
    PRINT 423
423 FORMAT ( 1X,' STOPPED AT 423 IN TRANS')
    STOP
422 JJ=J
    ILC=ILC+1
```

```
      LC(ILC)=JJ
      SSCC=CTTM-CTLOC(JJ)
      CTLOC(JJ)=CTLOC(JJ)+SSCC
      TLOC4(JJ)=TLOC4(JJ)+SSCC
  420 CONTINUE
      GO TO 340
  146 IF ( LS(NS+1) .EQ. 0  .OR. LS(NS+1) .EQ. 1) GO TO 147
      IF ( ILC .EQ. 0) GO TO 150
      NNSS=NS+1
      DO 352 I=1, NLOCO
  352 IF ( LL(I) .EQ. NNSS) GO TO 353
      PRINT 354, NNSS
  354 FORMAT ( 1X,' STOPPED AT 345 IN TRANS', I5)
      STOP
  353 II=I
      IF ( LOAD(II) .EQ. 0) GO TO 356
      J1=II+1
      DO 355 K=J1,NLOCO
  355 IF ( LL(K) .EQ. NNSS) GO TO 357
      PRINT 354, NNSS
      STOP
  357 II=K
  356 DO 358 I=1,ILC
  358 IF ( LC(I) .EQ. II) GO TO 359
      GO TO 150
  359 SSCC=CTTM-CTLOC(NL)
      TLOC4(NL)=TLOC4(NL)+SSCC
      CTLOC(NL)=CTLOC(NL)+SSCC
      ILC=ILC+1
      LC(ILC)=NL
      IF ( IL .EQ. 0) GO TO 340
      DO 370 J=1,IL
      JJ=LW(J)
      LW(J)=0
      TLOC4(JJ)=TLOC4(JJ)+(CTTM-CTLOC(JJ))
      CTLOC(JJ)=CTLOC(JJ)+(CTTM-CTLOC(JJ))
      ILC=ILC+1
  370 LC(ILC)=JJ
      IL=0
      GO TO 340
  147 NLDE=NLDE-1
      DO 148 I=1,NLOCO
      IF ( IDE(I) .EQ. 0) GO TO 148
      IDE(I)=IDE(I)-1
  148 CONTINUE
C
      CALL MOTION ( NL,NS)
C
      CTLOC(NL)=CTLOC(NL)+TIME(NL)/60.0
      NS=NS+1
      LL(NL)=NS
      LS(NS)=LS(NS)+2
```

```
      IF ( LOGPRT .NE. 0) GO TO 165
      NS1=NS-1
      NS2=NS
      PRINT 411
      PRINT 412, NL,CTLOC(NL),NS1,NS2,LOAD(NL)
  165 IF ( IL .EQ. 0) GO TO 300
      DO 151 I=1,IL
      JJ=LW(I)
      LW(I)=0
      CTLOC(JJ)=CTLOC(JJ)+TIME(NL)/60.0
  151 TLOC4(JJ)=TLOC4(JJ)+TIME(NL)/60.0
      IL=0
      GO TO 300
C
C     TRAIN LOADED
C
  123 NS=LL(NL)
      IF ( NS .EQ. 1) GO TO 155
      IF ( NS .EQ. NSW) GO TO 156
      IF ( NS .EQ. 2) GO TO 157
      IF ( LS(NS-1) .EQ. 1  .OR.  LS(NS-1) .EQ. 3) GO TO 460
      GO TO 157
  460 IF ( ILC .EQ. 0) GO TO 129
      NSS=NS-1
      DO 462 I=1,NLOCO
  462 IF ( LL(I) .EQ. NSS) GO TO 463
      PRINT 464, NSS
  464 FORMAT (1X,'STOPPED AT 464 IN TRANS', I5)
      STOP
  463 II=I
      IF ( LOAD(II) .EQ. 1) GO TO 466
      J1=II+1
      DO 465 K=J1,NLOCO
  465 IF ( LL(K) .EQ. NSS) GO TO 467
      PRINT 464, NSS
      STOP
  467 II=K
  466 DO 468 I=1,ILC
  468 IF ( LC(I) .EQ. II) GO TO 469
      GO TO 129
  469 ILC=ILC+1
      LC(ILC)=NL
      IDLC=1
      GO TO 129
  157 CTLOC(NL)=CTLOC(NL) +TPASS(NL)/60.0
      DISTR(NL)=DISTR(NL)+DSTOP(NL)
      TLOC3(NL)=TLOC3(NL)+TPASS(NL)/60.0
      LS(NS)=LS(NS)-1
C
      CALL MOTION(NL,NS)
C
```

```
      CTLOC(NL)=CTLOC(NL)+TIME(NL)/60.0
      TLOC3(NL)=TLOC3(NL)+TIME(NL)/60.0
      NS=NS-1
      LL(NL)=NS
      LS(NS)=LS(NS)+1
      IF ( LOGPRT .NE. 0) GO TO 414
      NS1=NS+1
      NS2=NS
      PRINT 411
      PRINT 412, NL,CTLOC(NL),NS1,NS2,LOAD(NL)
  414 IF ( NS .EQ. 1) GO TO 160
      IF ( IL .EQ. 0) GO TO 300
      IF (LIL .EQ. 0 ) GO TO 525
      DO 162 I=1,IL
      DO 528 J=1,LIL
  528 IF ( LW(I) .EQ. LLW(J)) GO TO 529
      ATPS=0.0
      GO TO 530
  529 ATPS=FTPS
  530 JJ=LW(I)
      CTLOC(JJ)=CTLOC(JJ)+ATPS+TIME(NL)/60.0
  162 TLOC4(JJ)=TLOC4(JJ)+ATPS+TIME(NL)/60.0
      DO 531 I=1,IL
      DO 532 J=1,LIL
  532 IF ( LW(I) .EQ. LLW(J)) GO TO 531
      LIL=LIL+1
      LLW(LIL)=LW(I)
  531 CONTINUE
      FTPS=TSTOP(NL)/60.0
      DO 37 I=1,IL
   37 LW(I)=0
      IL=0
      GO TO 300
  525 DO 526 I=1,IL
      JJ=LW(I)
      CTLOC(JJ)=CTLOC(JJ)+TIME(NL)/60.0
  526 TLOC4(JJ)=TLOC4(JJ)+TIME(NL)/60.0
      LIL=IL
      FTPS=TSTOP(NL)/60.0
      DO 527 I=1,LIL
  527 LLW(I)=LW(I)
      DO 38 I=1,IL
   38 LW(I)=0
      IL=0
      GO TO 300
  160 CTLOC(NL)=CTLOC(NL)+TSTOP(NL)/60.0
      DISTR(NL)=DISTR(NL)+DSTOP(NL)
      TLOC3(NL)=TLOC3(NL)+TSTOP(NL)/60.0
      SPEED(NL)=0.0
      NLDL=NLDL+1
      IDL(NL)=NLDL
```

```
      IF ( IL .EQ. 0) GO TO 159
      DO 163 I=1,IL
      JJ=LW(I)
      LW(I)=0
      CTLOC(JJ)=CTLOC(JJ)+TSTOP(NL)/60.0+TIME(NL)/60.0
  163 TLOC4(JJ)=TLOC4(JJ)+TSTOP(NL)/60.0+TIME(NL)/60.0
      IL=0
  159 IF ( NLDL .EQ. 1) GO TO 161
      GO TO 300
C
  161 CALL DUMP(NL)
C
      CTLOC(NL)=CTLOC(NL)+TDUMP(NL)
      TLOC2(NL)=TLOC2(NL)+TDUMP(NL)
      NLDL=NLDL-1
      IDL(NL)=IDL(NL)-1
      NLDE=NLDE+1
      IDE(NL)=NLDE
      LS(NS)=LS(NS)-1
      WTTRN(NL)=WTTRN(NL)-WTLOAD(NL)
      WTD=WTD+WTLOAD(NL)
      WTLOAD(NL)=0.0
      GO TO 300
  156 IF ( LS(NS-1) .EQ. 1  .OR. LS(NS-1) .EQ. 3) GO TO 500
      GO TO 511
  500 IF ( ILC .EQ. 0) GO TO 150
      NNSS=NS-1
      DO 501 I=1,NLOCO
  501 IF ( LL(I) .EQ. NNSS) GO TO 502
      PRINT 503
  503 FORMAT ( 1X,'STOPPED AT 503 IN TRANS')
      STOP
  502 II=I
      IF ( LOAD(II) .EQ. 1) GO TO 504
      J1=II+1
      DO 505 K=J1,NLOCO
  505 IF ( LL(K) .EQ. NNSS) GO TO 506
      PRINT 507
  507 FORMAT ( 1X,'STOPPED AT 507 IN TRANS')
      STOP
  506 II=K
  504 DO 508 I=1,ILC
  508 IF ( LC(I) .EQ. II) GO TO 509
      GO TO 150
  509 SSCC=CTTM-CTLOC(NL)
      TLOC4(NL)=TLOC4(NL)+SSCC
      CTLOC(NL)=CTLOC(NL)+SSCC
      ILC=ILC+1
      LC(ILC)=NL
      IF ( IL .EQ. 0) GO TO 340
      DO 510 J=1,IL
```

```
      JJ=LW(J)
      LW(J)=0
      TLOC4(JJ)=TLOC4(JJ)+(CTTM-CTLOC(JJ))
      CTLOC(JJ)=CTLOC(JJ)+(CTTM-CTLOC(JJ))
      ILC=ILC+1
  510 LC(ILC)=JJ
      IL=0
      GO TO 340
  511 LS(NS)=LS(NS)-1
C
      CALL MOTION ( NL,NS)
C
      NS=NS-1
      LS(NS)=LS(NS)+1
      LL(NL)=NS
      CTLOC(NL)=CTLOC(NL)+TIME(NL)/60.0
      TLOC3(NL)=TLOC3(NL)+TIME(NL)/60.0
      IF ( LOGPRT .NE. 0) GO TO 165
      NS1=NS+1
      NS2=NS
      PRINT 411
      PRINT 412, NL,CTLOC(NL),NS1,NS2,LOAD(NL)
      GO TO 165
  155 NLDL=NLDL+1
      IDL(NL)=NLDL
      IF ( NLDL .EQ. 1) GO TO 167
      IF (IDL(NL) .EQ. 1) GO TO 168
      IF ( ILC .EQ. 0) GO TO 150
      N11=IDL(NL)-1
      DO 381 I=1,N11
      DO 382 J=1,NLOCO
  382 IF ( IDL(J) .EQ. I) GO TO 383
      PRINT 384, I
  384 FORMAT ( 1X,'STOPPED AT 384 IN TRANS', I5)
      STOP
  383 JNL=J
      DO 385 K=1,ILC
  385 IF ( JNL .EQ. LC(K)) GO TO 386
      GO TO 381
  386 ILC=ILC+1
      LC(ILC)=NL
      SSCC=CTTM-CTLOC(NL)
      CTLOC(NL)=CTLOC(NL)+SSCC
      TLOC4(NL)=TLOC4(NL)+SSCC
      IF ( IL .EQ. 0) GO TO 391
      DO 392 K=1,IL
      JJ=LW(K)
      LW(K)=0
      ILC=ILC+1
      LC(ILC)=JJ
      TLOC4(JJ)=TLOC4(JJ)+(CTTM-CTLOC(JJ))
  392 CTLOC(JJ)=CTLOC(JJ)+(CTTM-CTLOC(JJ))
```

```
      IL=0
  391 IF ( I .EQ. N11) GO TO 426
      N10=I+1
      GO TO 387
  381 CONTINUE
      GO TO 150
  387 DO 388 L=N10,N11
      DO 389 J=1,NLOCO
  389 IF ( IDL(J) .EQ. L) GO TO 400
      PRINT 401
  401 FORMAT ( 1X, 'STOPPED AT 401 IN TRANS')
      STOP
  400 JJ=J
      TLOC4(JJ)=TLOC4(JJ)+(CTTM-CTLOC(JJ))
      CTLOC(JJ)=CTLOC(JJ)+(CTTM-CTLOC(JJ))
      ILC=ILC+1
      LC(ILC)=JJ
  388 CONTINUE
  426 IF ( IDL(NL) .EQ. NLDL) GO TO 340
      N13=IDL(NL)+1
      DO 430 I=N13,NLDL
      DO 431 J=1,NLOCO
  431 IF ( IDL(J) .EQ. I) GO TO 432
      PRINT 433
  433 FORMAT ( 1X,'STOPPED AT 433 IN TRANS')
      STOP
  432 JJ=J
      ILC=ILC+1
      LC(ILC)=JJ
      SSCC=CTTM-CTLOC(JJ)
      CTLOC(JJ)=CTLOC(JJ)+SSCC
      TLOC4(JJ)=TLOC4(JJ)+SSCC
  430 CONTINUE
      GO TO 340
  167 IF ( LS(NS) .EQ. 1) GO TO      169
      LS(NS)=LS(NS)-1
      GO TO 166
  169 LS(NS)=LS(NS)+1
      GO TO 166
  168 IF ( LS(NS) .EQ. 3 ) GO TO 166
      LS(NS)=LS(NS)+2
C
  166 CALL DUMP(NL)
C
      CTLOC(NL)=CTLOC(NL)+TDUMP(NL)
      TLOC2(NL)=TLOC2(NL)+TDUMP(NL)
      NLDL=NLDL-1
      NLDE=NLDE+1
      IDE(NL)=NLDE
```

```
      WTD=WTD+WTLOAD(NL)
      WTTRN(NL)=WTTRN(NL)-WTLOAD(NL)
      WTLOAD(NL)=0.0
      IF (NLDL .EQ. 1) GO TO 170
      DO 171 I=1,NLOCO
      IF ( IDL(I) .EQ. 0) GO TO 171
      IDL(I)=IDL(I)-1
  171 CONTINUE
      GO TO 172
  170 IDL(NL)=IDL(NL)-1
  172 IF ( IL .EQ. 0) GO TO 300
      DO 173 I=1,IL
      JJ=LW(I)
      LW(I)=0
      CTLOC(JJ)=CTLOC(JJ)+TDUMP(NL)
  173 TLOC4(JJ)=TLOC4(JJ)+TDUMP(NL)
      IL=0
      GO TO 300
  300 DO 175 I=1,NLOCO
  175 IF ( CTLOC(I) .GE. TIMAX ) GO TO 176
      IF ( IDLOAD .EQ. 0) GO TO 301
      IF ( ILWTID .EQ. 1  .AND.  NL .LT. NLOCO ) GO TO 301
      CTTM=CTIME + SCCTM
      IF ( ILC .EQ. 0) GO TO 733
      DO 734 I=1,NLOCO
      DO 735 J=1,ILC
  735 IF ( I .EQ. LC(J)) GO TO 734
      IF ( CTLOC(I) .LT. CTTM) GO TO 734
      ILC=ILC+1
      LC(ILC)=I
  734 CONTINUE
      GO TO 736
  733 DO 720 I=1,NLOCO
      IF ( CTLOC(I) .LT. CTTM) GO TO 720
      ILC=ILC+1
      LC(ILC)=I
  720 CONTINUE
  736 IF ( ILC .EQ. 0) GO TO 301
  340 IF ( ILC .GE. NLOCO) GO TO 701
C
C     FIND THE SMALLEST VALUE OF CTLOC(I) EXCEPT FOR CTLOC(ILC)
C
      M=1
  727 DO 725 I=1,ILC
  725 IF ( M .EQ. LC(I)) GO TO 726
      GO TO 728
  726 M=M+1
      GO TO 727
  728 M1=M+1
      IF ( M1 .GT. NLOCO) GO TO 841
      DO 729 I=M1,NLOCO
      MJ=I
```

```
      DO 730 J=1,ILC
  730 IF ( MJ .EQ. LC(J)) GO TO 729
      IF ( CTLOC(M) .LE. CTLOC(MJ)) GO TO 729
      M=MJ
  729 CONTINUE
  841 NL=M
      GO TO 200
  176 PRINT 177
  177 FORMAT ( 1H0,'SIMULATION TERMINATED BY MAX CLOCK TIME ALLOWED')
      IDEOS=1
      GO TO 701
C
C     PRINT THE SUMMARY OF SIMULATION AT THE END OF RUN
C
  299 PRINT 193,HAUL,WTG,WTD
  193 FORMAT ( 1H1,'LENGTH OF HAULAGE LINE=',F12.3/' ','WT OF MUCK GENER
     $ATED=', F12.3/' ', 'WT OF MUCK DUMPED=',F12.3 //)
      PRINT 194
  194 FORMAT (1H1, 'LOCO NO.  CLOCK TIME  LOADING TIME DUMPING TIME RUNN
     $ING TIME WAITING TIME DISTANCE TRAVELED')
      DO 195 I=1,NLOCO
      CTLOC(I)=CTLOC(I)/60.0
      TLOC1(I)=TLOC1(I)/60.0
      TLOC2(I)=TLOC2(I)/60.0
      TLOC3(I)=TLOC3(I)/60.0
      TLOC4(I)=TLOC4(I)/60.0
  195 PRINT 196, I,CTLOC(I),TLOC1(I),TLOC2(I),TLOC3(I),TLOC4(I),DISTR(I)
  196 FORMAT (2X,I3,3X,F12.3, 4(3X,F10.3), F15.3)
      IDEOS=1
  701 RETURN
      END
```

COMPILATION: NO DIAGNOSTICS.